

SECTION 3

Summary of 1999 and 2000 Monitoring Data

This section summarizes data from the ambient, point source, and MOSS monitoring programs collected in 1999 and 2000. A total of 73 stations were sampled in 1999 and 70 were sampled in 2000. All data for stations monitored are presented in Appendices A through F. Station locator maps are provided in Section 2, along with specific station information such as matrix, parameters, and frequency measured. Also included in this section is a summary of 1999 and 2000 precipitation data as pollutants, particularly bacteria, are introduced into nearshore and offshore waters following rainstorms.

A summary of the results for specific parameters (e.g., salinity, bacteria, metals) and matrices (e.g., water, sediment, shellfish) are provided. A discussion of the results for the ambient, point source, and MOSS samples are combined in order to facilitate the interpretation of the data. Each matrix will be discussed separately.

3.1 Precipitation Data

Monthly total precipitation data for 1999 and 2000 were obtained from the National Climatic Data Center and are shown in Figures 3-1 and 3-2. The rainfall totals were measured at the Sea-Tac International Airport station and the data do not include snow or ice pellet accumulations, as the 30-year average does not include these data.

3.1.1 1999 Precipitation

1999 precipitation was typical of the rainfall patterns observed over the last 30 years in the King County region. The annual rainfall total (42.11 inches) is consistent with the 30-year average and the 5-year average (37.08 in. and 41.76 in., respectively). Rainfall totals were greatest during the winter months (January-February, November-December) and lowest during late spring through early fall (May through September). With the exception of a moderately wet November (9.6 inches) and a dry September (0.17 inches), monthly rainfall totals generally correspond to the 30-year average. The slightly elevated totals in January and February of 1999 are consistent with the remaining effects of the 1998-1999 La Nina weather event.

3.1.2 2000 Precipitation

2000 annual precipitation was the fourth lowest annual total (28.66 in.) in the last 30 years. The monthly totals only exceeded the 30-year average three times, February, May and June. July, August and September were notably dry with only 1.68 in. during the three-month period. Similarly, November and December produced rainfall totals approximately half of the 30-year

average. The lower than normal rainfall in 2000 does not appear to be a consequence of the El Nino/La Nina phenomenon. The year 2000 was classified as normal (“nada” Nino) although the 1998-1999 La Nina event was slow to degrade and sea surface temperatures of the equatorial Pacific returned to normal in August of 2000. There is no indication of a building El Nino event that would account for the dry winter of 2000.

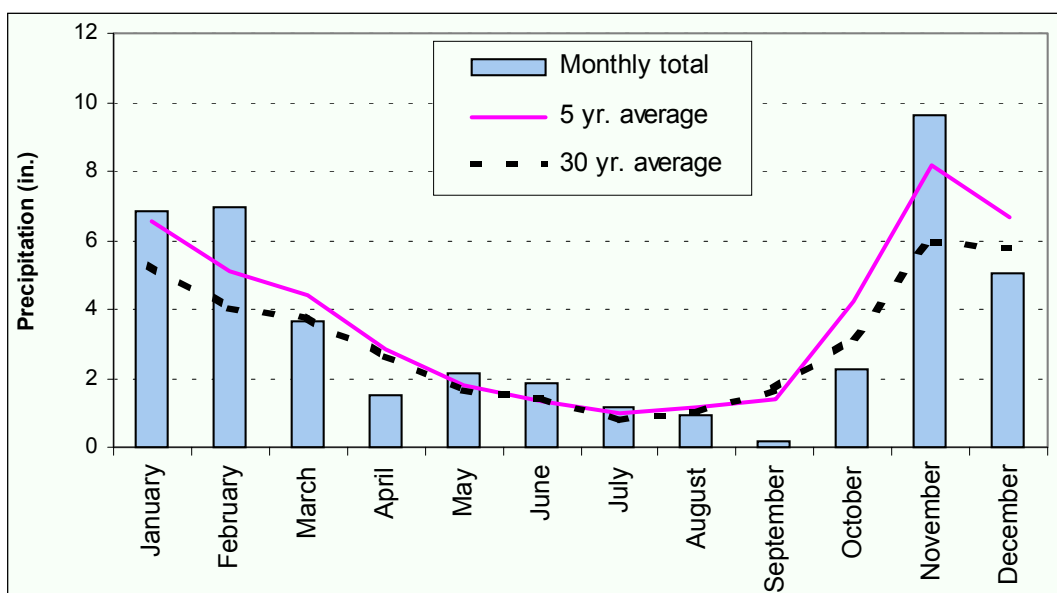


Figure 3-1. Monthly Precipitation for 1999

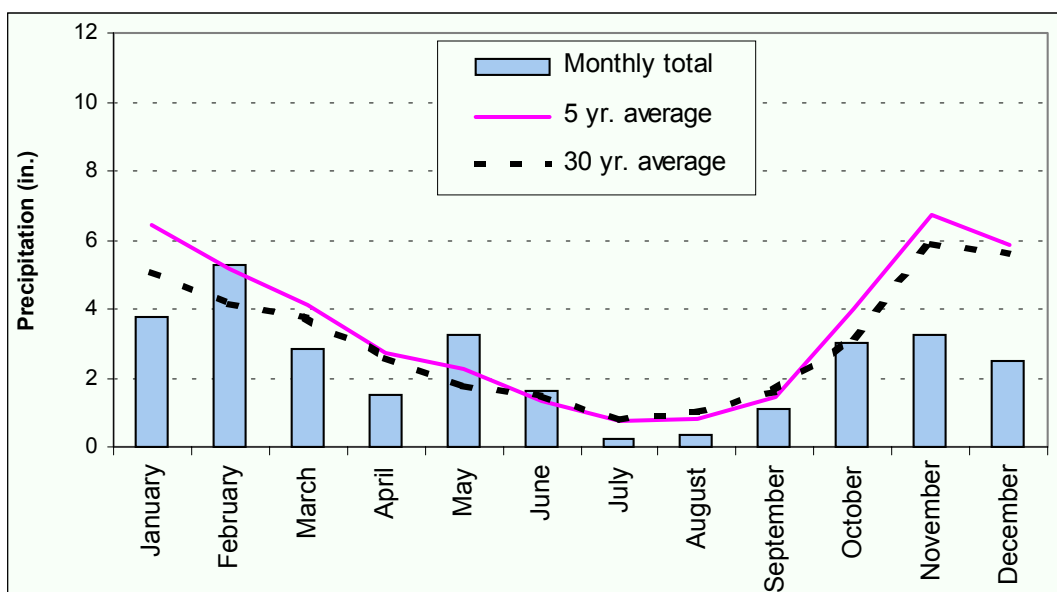


Figure 3-2. Monthly Precipitation for 2000

3.2 Water Column Data Results

Water column sampling is a large component of the County's water quality monitoring program and includes offshore, nearshore, and beach sites (see Figure 2-2 and 2-3). The monitoring program is structured to detect natural seasonal changes in the water column and also to identify anthropogenic inputs and influences.

Water quality parameters, including temperature, salinity, turbidity, dissolved oxygen, total suspended solids, Secchi disk transparency, light intensity, chlorophyll-*a*, pheophytin, and nutrients (ammonia, nitrate+nitrite, and total phosphorus) were measured at 12 offshore/nearshore stations in 1999 and at 15 stations in 2000. Temperature, salinity and nutrients were measured at 19 nearshore and beach stations in 1999 and at 27 stations in 2000.

Bacteria (fecal coliform and enterococcus) were monitored at 21 beach stations and 14 offshore/nearshore stations in 1999. Fecal coliform and enterococcus bacteria were monitored at 29 beach stations and 17 offshore/nearshore stations in 2000. *E. coli* was also monitored at 8 offshore stations in 1999 and at 8 offshore and 14 beach stations in 2000.

3.2.1 Water Column Bacteria

Both fecal coliform and enterococcus bacteria were monitored at all water stations, with the exception of one station (OMHB) located near Suquamish. *E. coli* were monitored for the MOSS stations only. Data from the two freshwater stations (KTHA01 and KSRU02) are compared to freshwater bacteria standards and all other stations are compared to the saltwater standards. Washington State marine Class AA fecal coliform standards for surface waters state that organism counts shall not exceed a geometric mean value of 14 colonies/100 ml and not more than 10 percent of the samples used to calculate the geometric mean may exceed 43 colonies/100 ml. Freshwater Class AA fecal coliform standards state that organism counts shall not exceed a geometric mean value of 50 colonies/100 ml and not more than 10 percent of the samples used for calculating the geometric mean may exceed 100 colonies/100 ml (WAC 173-201, 1991). King County uses results from the 30 most recent samples (surface samples only) to obtain a geometric mean values as per the guidelines in the National Shellfish Sanitation Program (NSSP, 1995). Surface samples are used as these tend to be the highest values and represents the area where most contact occurs with people and intertidal organisms.

Offshore/Nearshore. All of the offshore/nearshore water column stations met Class AA fecal coliform water standards in both 1999 and 2000 with the exception of two stations located in inner Elliott Bay: LTBC41 and LTED04 (Tables 3-1 and 3-2). Fecal coliform counts at these stations met the geometric mean but did not meet the peak standard for both years, which is similar to results from previous years sampling. For station LTBC41, 5 of the last 30 samples exceeded 43 cfu/100 ml and for station LTED04, 4 of the last 30 samples exceeded 43 cfu/100 ml. At both these stations, exceedences of the peak standard occurred when rain fell prior to sampling. Both these stations receive higher freshwater input than other offshore/nearshore stations due to their proximity to the Duwamish River. Results from the MOSS stations,

including the Admiralty Inlet and Possession Sound stations, were similar to other offshore stations, with low levels of fecal coliform bacteria detected, if at all.

Table 3-1. 1999 and 2000 Ambient Monitoring--Fecal Coliform Bacteria

Station	Meets Class AA Marine Water Standards				Comments
	Geometric mean (14 colonies/100 ml)		Peak ^a (43 colonies/100 ml)		
Beach	1999	2000	1999	2000	
Stations north of Ship Canal					
JSWX01	Yes	Yes	No	No	4 of the last 30 samples are > 43 colonies/100 ml.
JSVW04	Yes	Yes	No	No	5 of the last 30 samples are > 43 colonies/100 ml.
KSLU03	No	No	No	No	11 of the last 30 samples are > 43 colonies/100 ml.
KSQU01	No	No	No	No	7 of last 30 samples are > 43 col./100 ml. Near Ship Canal.
KRJY01 ^b	Yes	Yes	Yes	Yes	Sampled from May to September.
ITPICNICPT ^b	--	Yes	--	Yes	Located at Picnic Point.
ITMEADOWBP ^b	--	Yes	--	Yes	Located at Meadowdale Beach Park.
ITOCEANAVE ^b	--	Yes	--	Yes	Located near Ocean Avenue-north of Brackett's Landing.
ITBRACKETT ^b	--	No	--	No	7 of 10 samples are > 43 colonies/100 ml.
ITEDWARDSPT ^b	--	Yes	--	Yes	Located at Edward's Point.
ITBOEINGCR ^b	--	Yes	--	Yes	Located near Boeing Creek.
ITCARKEEK ^b	--	Yes	--	Yes	Located at Carkeek Park.
KSJX02 ^b	--	Yes	--	Yes	Located near Blue Ridge.
Stations between Ship Canal and Alki Point					
KSYV02	No	No	No	No	9 of the last 30 samples are > 43 colonies/100 ml.
LTAB01	No	Yes	No	Yes	2 of the last 30 samples are > 43 colonies/100 ml.
LTEH02	No	No	No	No	9 of last 30 samples are > 43 col./100 ml. Inner Elliott Bay stn.
LSGY01	Yes	Yes	Yes	Yes	Duwamish Head area
LSFX01	Yes	Yes	Yes	Yes	Seacrest Park area
LSHV01	Yes	Yes	Yes	Yes	Located north of Alki Point near Alki Drive.
Stations south of Alki Point					
LSVW01	No	No	No	No	19 of last 30 samples are >43 col./100 ml.
LSTU01	Yes	Yes	Yes	Yes	Near Lincoln Park.
MTEC01	Yes	Yes	No	No	Sampled May through October
MSSM05	No	No	No	No	Sampled May through October
MTLD03 ^b	Yes	Yes	Yes	No	Only 12 samples. 3 of 12 samples > 43 colonies/100 ml.
Offshore/Nearshore					
ADMIRALC14 ^b	Yes	Yes	Yes	Yes	Station is located in Admiralty Inlet.
POSSESC14 ^b	Yes	Yes	Yes	Yes	Station is located in southern Possession Sound.
PtWells1 ^b	Yes	Yes	Yes	Yes	Station is located off Point Wells.
KSBP01	Yes	Yes	Yes	Yes	Station is between Carkeek Park and Jefferson Head.
KSRU02 ^c	Yes	Yes	Yes	Yes	Station is located in the Lake Washington Ship Canal.
LTED04	Yes	Yes	No	No	4 of the last 30 samples are > 43 colonies/100 ml.
LSNT01	Yes	Yes	Yes	Yes	Station is north of Vashon Island.
COLVOPASS ^b	Yes	Yes	Yes	Yes	Station is located in northern Colvos Passage.
EDMDS-CTD2 ^b	--	Yes	--	Yes	Only 4 samples: September through December.
EDMDS-CTD4 ^b	--	Yes	--	Yes	Only 4 samples: September through December.
^a -- Not more than 10 percent of the 30 most recent samples may exceed this value.					
^b -- Geometric mean calculated with less than 30 samples.					
^c -- Station results are compared with Class AA freshwater standards which state the geometric mean value may not exceed 50 colonies/100ml and not more than 10 percent of the most 30 recent samples may exceed 100 colonies/100 ml.					

Table 3-2. 1999 and 2000 Point Source Monitoring--Fecal Coliform Bacteria

Station	Meets Class AA Marine Water Standards				Comments
	Geometric mean (14 colonies/100 ml)		Peak ^a (43 colonies/100 ml)		
Beach	1999	2000	1999	2000	
Carkeek Park					
KSHZ03	No	No	No	No	11 of last 30 samples are > 43 col./100 ml. Near mouth of Piper's Creek.
KTHA01 ^b	No	No	No	No	22 of last 30 samples are >100 col./100 ml. Freshwater station in Piper's Creek.
West Point					
KSSN04	Yes	Yes	No	Yes	Located north of the West Point lighthouse.
KSSN05	Yes	Yes	No	No	5 of last 30 samples are > 43 colonies/100 ml.
Alki					
LSKR01	No	Yes	No	No	8 of last 30 samples are > 43 colonies/100 ml.
LSKS01	No	No	No	No	16 of last 30 samples are > 43 colonies/100 ml.
Offshore/Nearshore					
Carkeek Park					
KSIW02	Yes	Yes	Yes	Yes	Station not sampled after May 2000. Station changed to CK200P.
CK200P	--	Yes	--	Yes	Sampled July through December. Geomean calculated with < 30 samples.
West Point					
KSSK02	Yes	Yes	Yes	Yes	Station near end of outfall pipe.
Denny Way					
LTBC41	Yes	Yes	No	No	5 of last 30 samples >43 col./100 ml.
Alki					
LSKQ06	Yes	Yes	Yes	Yes	Station is just off the Alki TP outfall.
South Plant outfall					
LSEP01	Yes	Yes	Yes	Yes	Station near end of north outfall pipe.
^a -- Not more than 10 percent of the 30 most recent samples may exceed this value.					
^b -- Station results are compared with Class AA freshwater standards which state the geometric mean value may not exceed 50 colonies/100ml and not more than 10 percent of the most 30 recent samples may exceed 100 colonies/100 ml.					

Fecal coliform bacteria in the water column near King County's treatment plant discharges were present at low levels, if detected at all, throughout most of the year. Figure 3-3 shows the concentrations of fecal coliform bacteria found at all offshore/nearshore stations in 1999 and 2000. For offshore stations, the highest concentrations are usually found at the surface. Starting in February 2000, only the surface depth was monitored at offshore/nearshore stations with the exception of the two stations at the West Point and South Plant outfalls (stations KSSK02 and LSEP01, respectively). All depths were monitored for bacteria at these two stations. Higher fecal coliform counts than have been seen in previous years were found at station KSSK02 in September 2000 at all depths monitored. Counts ranged from 21 (55 m depth) to 200 (25 m depth) cfu/100 ml. The West Point Treatment Plant was operating under normal conditions with no anomalies noted during this time and high counts were not noted during any other months during the two-year period.

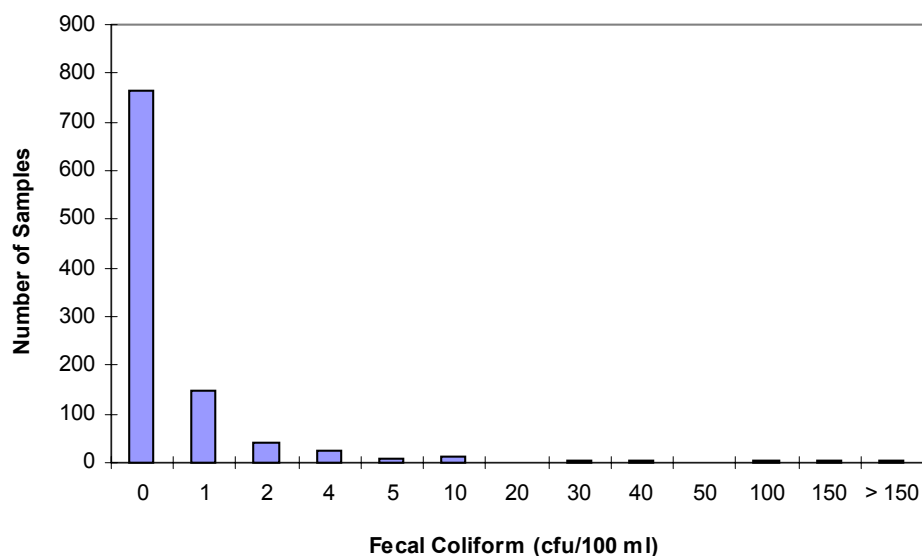


Figure 3-3. Fecal Coliform Bacteria at Offshore/Nearshore Stations in 1999 and 2000

Beaches. Fecal coliform concentrations in water samples from beaches are influenced by freshwater runoff and by waterfowl congregating in these areas. As a result, the number of stations exceeding the Class AA marine surface water standards increased during high rainfall months and at stations close to streams and other sources of freshwater runoff (Figure 3-4). Stations that are in areas with restricted water movement tend to retain freshwater input for a longer period of time and also frequently exceed standards. Stations in Tramp Harbor (MSSM05), inner Elliott Bay (LTEH02), Fauntleroy Cove (LSVW01), near the Lake Washington Ship Canal and Piper's Creek (KSQU01, KSHZ03, and KTHA01) have consistently failed both the geometric and peak standards for the last five years. The station located at Golden Gardens, north of the Ship Canal has also consistently failed both standards over the last five years. One of the MOSS beach stations located at Brackett's Landing (ITBRACKETT) failed both standards, however, sampling started in 2000 and less than 30 samples were used to calculate the geometric mean. Seven of the 10 samples collected at this station had fecal coliform values over 43 cfu/100 ml.

Beach stations from the routine monitoring program with the lowest fecal coliform counts were those near Seacrest Park, Duwamish Head, the north side of Alki Point, and the exposed beach station at Fay Bainbridge State Park. Bacteria levels at these three stations were below Class AA standards for both 1999 and 2000. These stations have consistently had low bacteria concentrations over the past several years. The station located near Lincoln Park met both the geometric mean and peak standard for both years. In past years, this station has met the geometric mean standard but failed the peak standard. All the MOSS beach stations, with the exception of the Brackett's Landing station, met both the geometric and peak standards in 2000 (see Table 3-1). The station near Boeing Creek had the lowest fecal coliform levels of all the MOSS and routine monitoring stations.

Figure 3-4. Fecal Coliform Results: Comparison With Standards

Several stations, including both Richmond Beach stations, Seahurst Park, and the southern West Point station, met the geometric mean standard for both years but failed the peak standard. The Richmond Beach, Seahurst Park, and West Point stations did not exceed the peak standard substantially and no more than 5 of the last 30 results exceeded 43 cfu/100 ml.

As with fecal coliform bacteria, enterococcus bacteria in offshore/nearshore water column samples were low, if detected at all, in both 1999 and 2000. There was no spatial trend detected from north to south and levels at the treatment plants outfalls were the same as the ambient stations, with one exception. Enterococcus counts at station KSSK02 for depths 1 to 25 m in September 2000 were higher than have been recorded in previous years. This same pattern was also observed with fecal coliform bacteria. Higher counts than typically observed were not noted during any other months during the two-year period for this station.

Enterococcus bacteria counts at beach stations varied from station to station and from month to month. Values tended to be higher in the higher rainfall months for both years, but did not show a consistent pattern with rainfall. The station near Boeing Creek had the lowest enterococcus concentrations of all the MOSS and routine monitoring stations and overall, enterococcus bacteria levels were lower than fecal coliform numbers. Figure 3-5 shows both fecal coliform and enterococcus bacteria results for beach stations in June 1999. This data pattern is typical for other months and for 2000 results. Generally, enterococcus bacteria counts were not elevated when fecal coliform results were high and overall did not correspond with fecal coliform results.

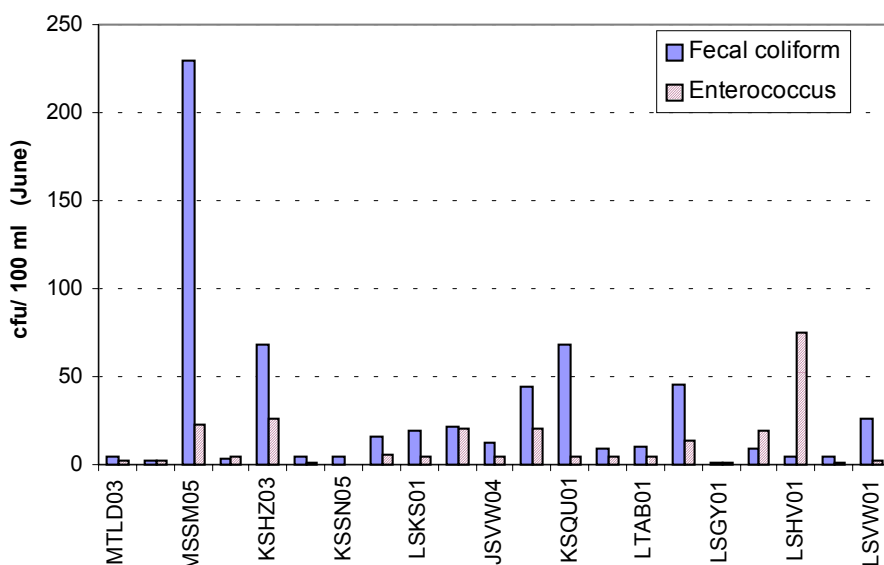


Figure 3-5. Bacteria Results for Beach Stations in 1999

E. coli was monitored for the MOSS project at 8 offshore stations in 1999 and 2000 and at 14 beach stations in 2000. As with fecal coliform and enterococcus bacteria, *E. coli* counts in offshore waters were detected at low levels, if at all. Figure 3-6 shows a frequency distribution plot for both 1999 and 2000 offshore data. Of the 889 samples analyzed, 833 values (94 %) were either 0 or 1 cfu/100 ml.

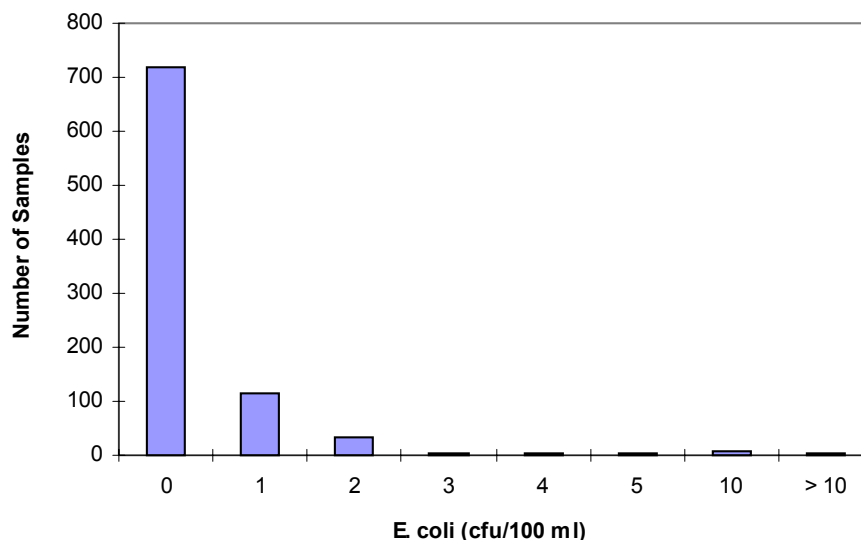


Figure 3-6. *E. coli* Results for All Offshore Stations in 1999 and 2000

E. coli values for beach stations varied with month and station and the highest proportion of values were between 10 to 50 cfu/100 ml (Figure 3-7). Boeing Creek, Meadowdale Beach Park, and the Carkeek stations had the lowest *E. coli* counts throughout the year. The highest single point values were detected at the Picnic Point station (1,500 cfu/100 ml) in December and the Richmond Beach station (3,000 cfu/100 ml) in October. The Brackett's Landing station (ITBRACKETT) had the highest values throughout the year of all the stations with counts ranging from 3 to 920 cfu/ 100 ml. Bacteria concentrations at this station were not associated with rainfall as demonstrated in Figure 3-8.

While enterococcus and fecal coliform bacteria values do not appear to be related, *E. coli* and fecal coliform bacteria for the 2000 beach stations do show a similarity when sampled concurrently. Both fecal coliform and *E. coli* bacteria are members of the same bacterial group while enterococcus is a part of the staphylococcus group. Figure 3-9 shows the fecal coliform, enterococcus, and *E. coli* bacteria levels measured at the Brackett's Landing station for 2000.

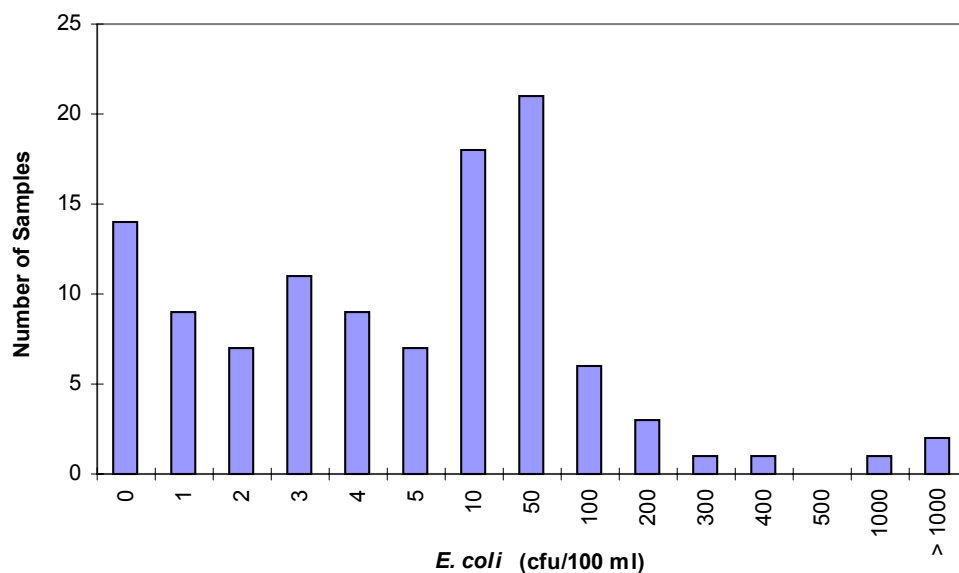


Figure 3-7. *E. coli* Results for Beach Stations in 2000

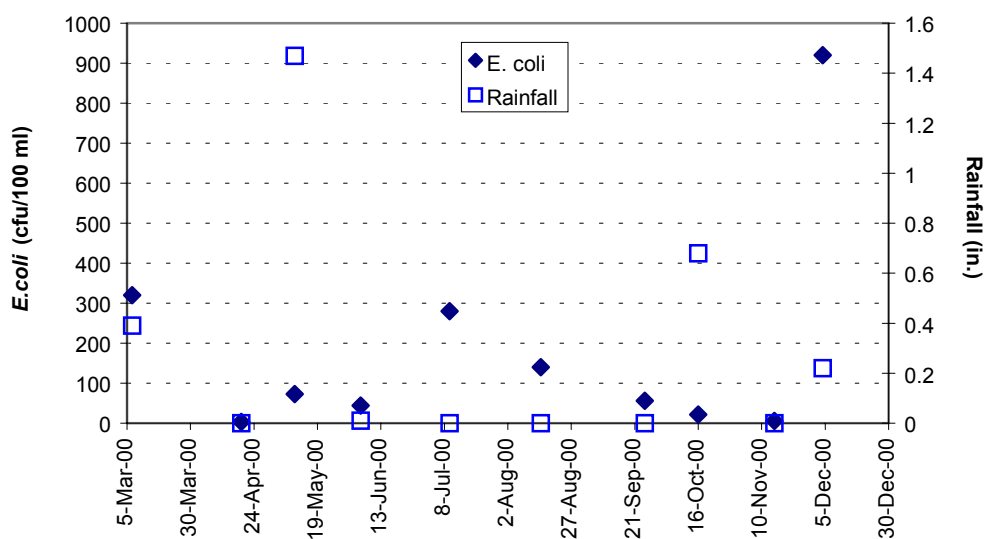


Figure 3-8. *E. coli* and Rainfall at Brackett's Landing in 2000

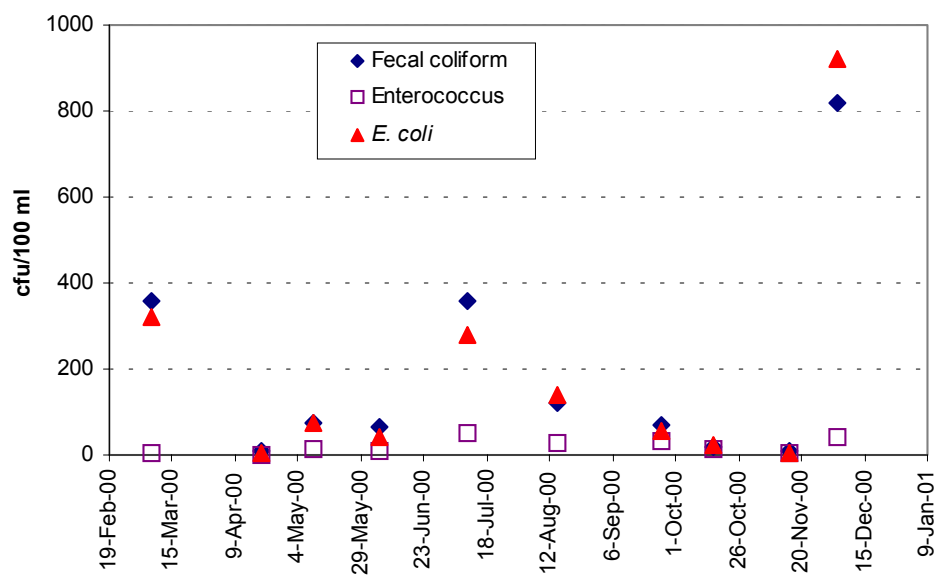


Figure 3-9. Bacteria at Brackett's Landing in 2000

3.2.2 Water Temperature

Temperature profiles were measured throughout the water column depending upon the depth of each offshore station. Depths ranged from just below the surface down to a maximum of 205 m. Temperatures from up to seven discrete water depths ranging from 1 to 205 m are provided in Appendix A. For offshore stations sampled in both 1999 and 2000, temperatures ranged from 7.5 to 14.7 (mean = 10.2) °C. Temperatures were similar between years with values ranging from 7.5 to 14.5 °C in 1999 and 7.6 to 14.7 °C in 2000. Water temperatures in 1999 and 2000 were lower than those measured in 1998. Temperatures ranged between 8.2 to 16.2 °C (mean = 11.2) in 1998, whereas the means for both 1999 and 2000 were a degree cooler indicating a return to typical temperatures following the warming noted as a result of the 1997 El Nino event.

For both 1999 and 2000, temperatures at offshore stations were coolest in March and then gradually warmed until they peaked in September before gradually cooling down again. Temperature variations during the winter and early spring months were slight, particularly at the deeper depths. Surface values varied more than other depths sampled due to weather influences, such as air temperature, cloud cover, and wind. The water column started to exhibit weak thermal stratification in June for both 1999 and 2000 which lasted through September. Figure 3-10 provides temperatures for six stations located throughout the sampling area in 2000. The patterns in these figures are typical for other stations monitored and for temperatures observed in 1999. The graphs show variations at the surface and the existence of a well-mixed water column at deeper depths even when seasonal stratification is present.

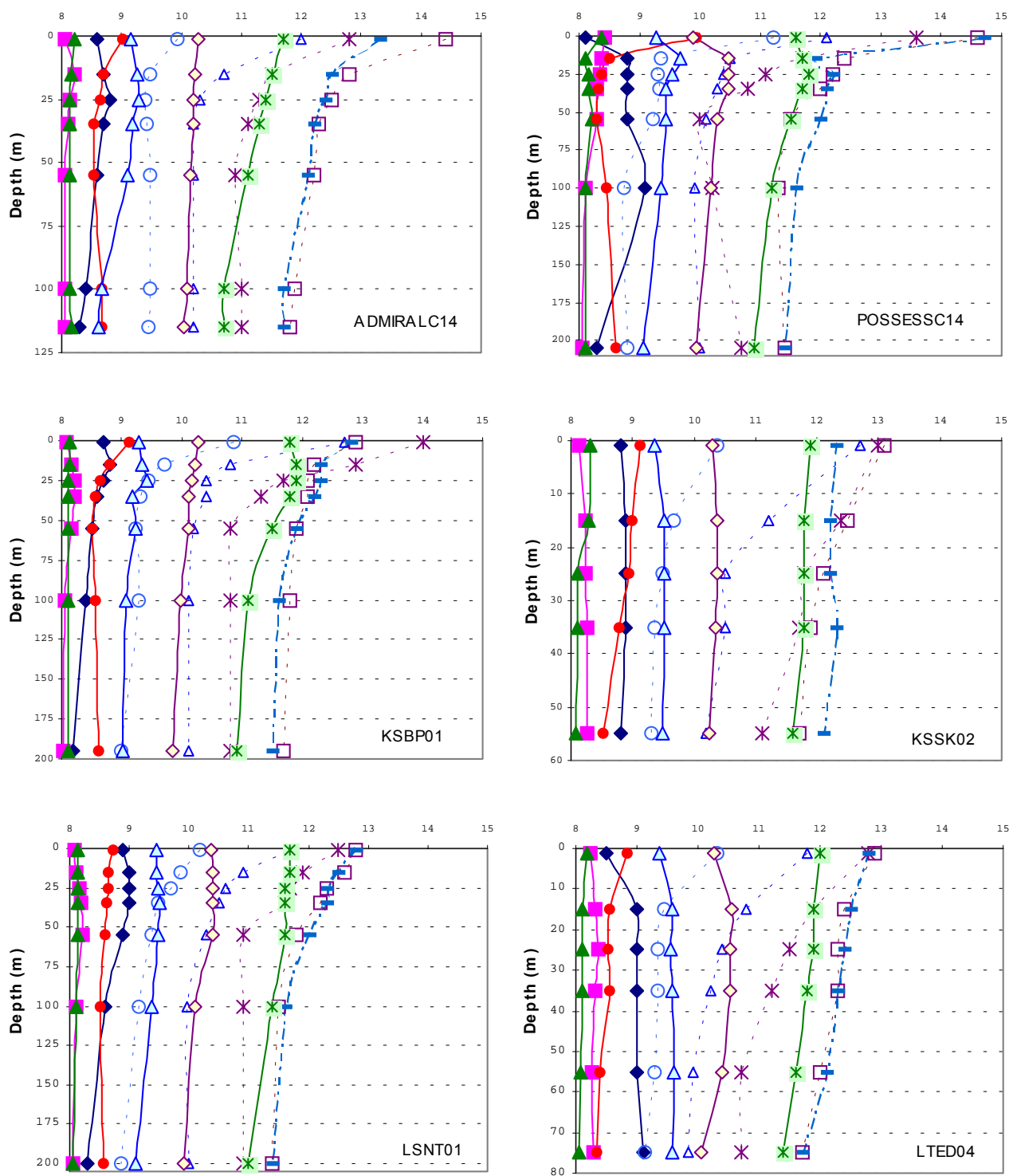


Figure 3-10. Water Temperature (°C) at Six Stations in 2000

Temperatures for beach stations sampled in both 1999 and 2000 ranged from 6.5 to 20.2 (mean = 11.3) °C. Temperatures were similar between years although eight additional stations (for the MOSS program) were sampled in 2000, with values ranging from 6.5 to 20.2 (mean = 11.2) °C in 1999 and 6.7 to 18.0 (mean = 11.3) °C in 2000. It should be noted, however, that sampling for the eight additional stations did not start until March 2000. Figure 3-11 shows the seasonal pattern for all beach stations with temperatures warming in the summer months and peaking in August. The highest value of 20.2 °C was recorded at station KSSN05 on the south side of West Point. A time-lag of approximately one month was noted in the peak temperatures between the beach and offshore stations with temperatures peaking in August for beach stations and in September for offshore stations. There was no notable difference between stations, with the exception of station LTAB01 located in inner Elliott Bay (Figure 3-11). This station had a slightly lower temperature average for both years as well as a lower maximum value recorded than other stations. This is likely due to the influence of colder water from the Duwamish River and the physical characteristics of the station—it has a steeper slope and the bottom drops off sharply.

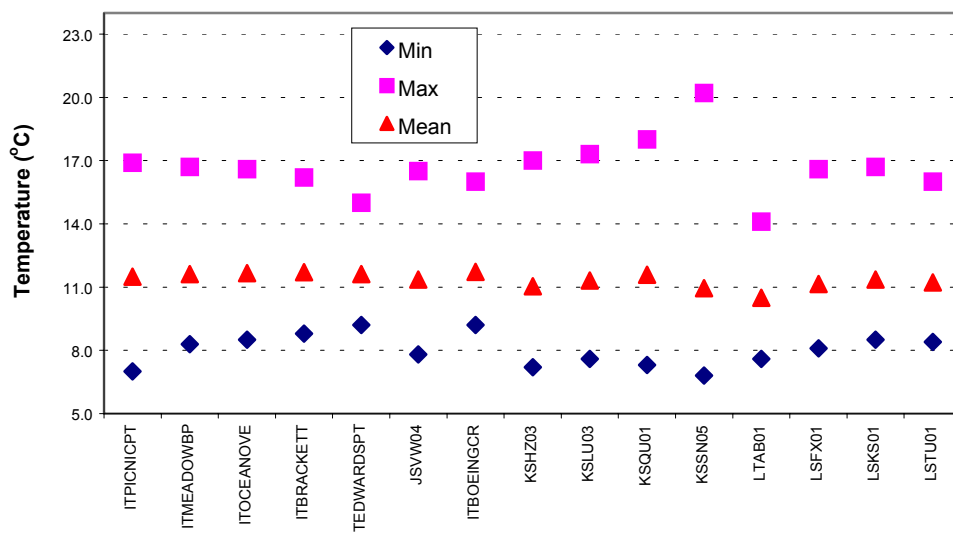


Figure 3-11. Water Temperature at Beach Stations in 2000

3.2.3 Salinity and Density

Salinity water column profiles were measured throughout the water column depending upon the depth of each offshore station. Salinity values in 1999 and 2000 from up to seven discrete water depths ranging from 1 to 205 m are provided in Appendix A and discussed below. Salinities in 1999 and 2000 ranged from 22.846 to 30.763 (mean = 29.076) on the Practical Salinity Scale (PSS) for all offshore stations except KSRU02. Station KSRU02 is located in the Lake

Washington Ship Canal just west of the Ballard Locks and the salinity at this station is tidally influenced and ranged between 9.732 and 19.114 PSS. Values at this station are for 1999 only, as salinity was not measured in 2000. Salinities exhibited only slight variations between 1999 and 2000 with values in 1999 ranging from 22.846 to 30.763 (mean = 29.103) PSS and from 24.840 to 29.989 (mean = 29.053) PSS in 2000.

Salinities varied due to seasonal influences as shown by the salinity profiles for six stations (Figure 3-12). Lower salinities were detected in surface waters during months when freshwater input was the highest for both years. The two inner Elliott Bay stations (LTBC41 and LTED04) had lower salinities at the surface throughout the year which is attributed to the freshwater influence of the Duwamish River. The lowest salinities measured were at the surface for the Admiralty Inlet and Possession Sound stations (ADMIRALC14 and POSSESSC14). The Admiralty Inlet station had a surface salinity of 22.846 PSS in November 1999 which is likely due to a freshwater layer exiting the Sound as the salinity measured at 15 m was 29.712 PSS. A surface value of 23.494 PSS at the Possession Sound station in February 1999 is also likely due to freshwater exiting the Sound from water flowing from the Skagit and Snohomish Rivers into and then out through Possession Sound. Possession Sound also had low salinities in May and June at the surface due to the high flows from the Snohomish and Skagit Rivers from snow melt. Unlike surface waters, salinities measured from 15 to 205 m showed little variation with depth, indicating a well-mixed water column. Salinities were highest from September to December and peaked in October, which may be attributed to the increased input of more saline deep oceanic water due to off-coast upwelling during late summer and a decrease in freshwater input from rivers and precipitation. The highest salinity value was measured at the deepest depth (205 m) at the Possession Sound station (POSSESSC14) in October 1999.

Salinities at beach stations ranged from 12.124 to 30.489 (mean = 27.661) PSS in 1999 and 2000. Values were similar for both years with mean salinities at 27.028 and 27.957 PSS in 1999 and 2000, respectively. The Brackett's Landing station had the highest measured salinity while the station at the mouth of the Ship Canal had the lowest. Salinities were lower at stations near a freshwater source as shown in Figure 3-13. Stations IIPICNICPT, KSHZ03, KSQU01, KSLU03, and LTAB01 are all either near a creek draining into the Sound, the Lake Washington Ship Canal, or within the influence of the Duwamish River. There was no notable difference among stations from north to south other than being near a freshwater source.

Salinities at beach stations were highest from September to November and peaked in October which is similar to the pattern observed at the offshore stations. However, salinities decreased in December unlike the offshore stations likely due to precipitation runoff. Salinities were lowest in April also indicating the influence of precipitation runoff.

Density affects vertical mixing processes in the water column. Both temperature and salinity affect water density, which generally increases with colder water or higher salinity. Density is important as the water column may stratify and trap nutrients and/or contaminants in differing density layers. Figure 3-14 presents density profiles for six offshore stations in 2000 which show patterns that are representative of the other stations monitored. For depths 15 m and greater, the water column shows little variation and stratification throughout the year. For stations in the main basin, densities were lower at the surface during certain months when freshwater input into

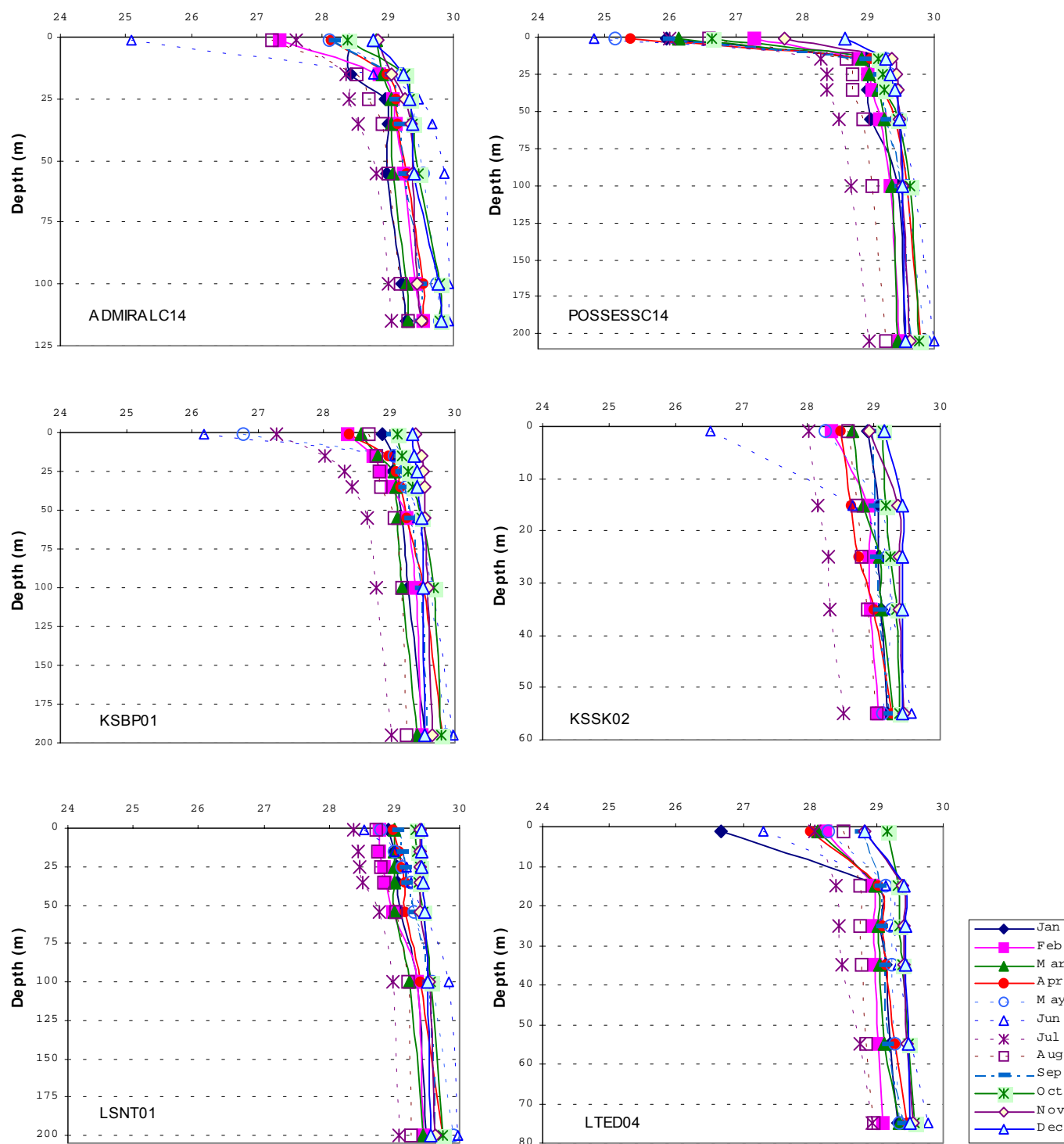


Figure 3-12. Salinity (PSS) at Six Stations in 2000

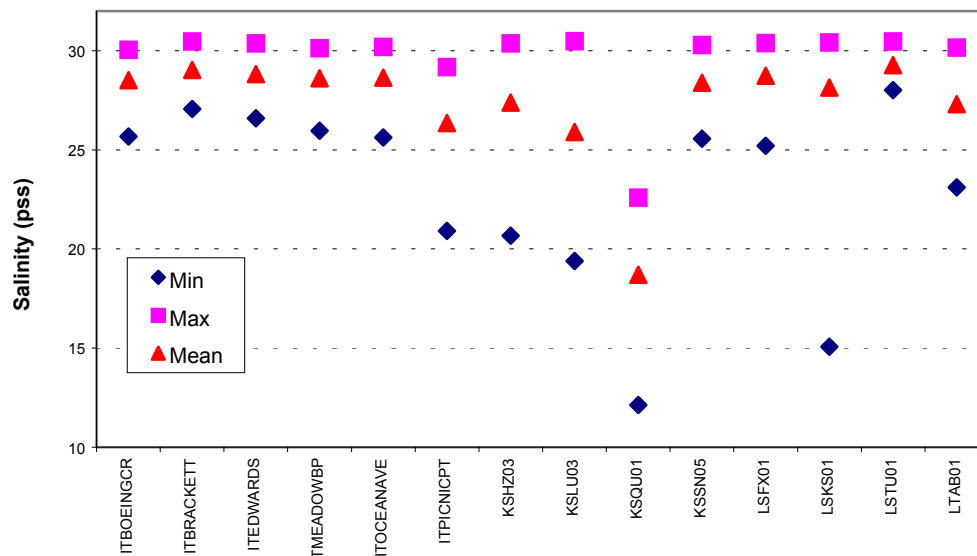


Figure 3-13. Salinity at Beach Stations in 2000

the Sound is higher. The Admiralty Inlet and Possession Sound stations had lower densities at the surface throughout most of the year, particularly in May and June when freshwater input into the Sound was greatest.

3.2.4 Dissolved Oxygen

Dissolved oxygen was measured throughout the water column depending upon the depth of each offshore station. Dissolved oxygen values in 1999 and 2000 from up to seven discrete water depths ranging from 1 to 205 m are discussed below. Concentrations for all stations sampled in both 1999 and 2000 ranged from 4.5 to 12.0 (mean = 7.2) mg/L. Values were similar between years and ranged from 4.5 to 12.0 (mean = 7.4) mg/L in 1999 and from 4.7 to 10.9 (mean = 7.1) mg/L in 2000. Figure 3-15 provides a frequency plot for concentrations measured at all stations in 1999 and 2000. Concentrations decreased with depth as most of the oxygen in estuaries is obtained from atmospheric input across the air-sea interface and photosynthetic activity (Kennish, 1994). The mean for all concentrations in 1999 and 2000 at the surface was 8.2 mg/L compared with a mean of 6.6 mg/L for the 200 m depth. Figure 3-16 shows dissolved oxygen profiles for six stations in 2000 which are representative of the patterns show in 1999 and at other stations sampled.

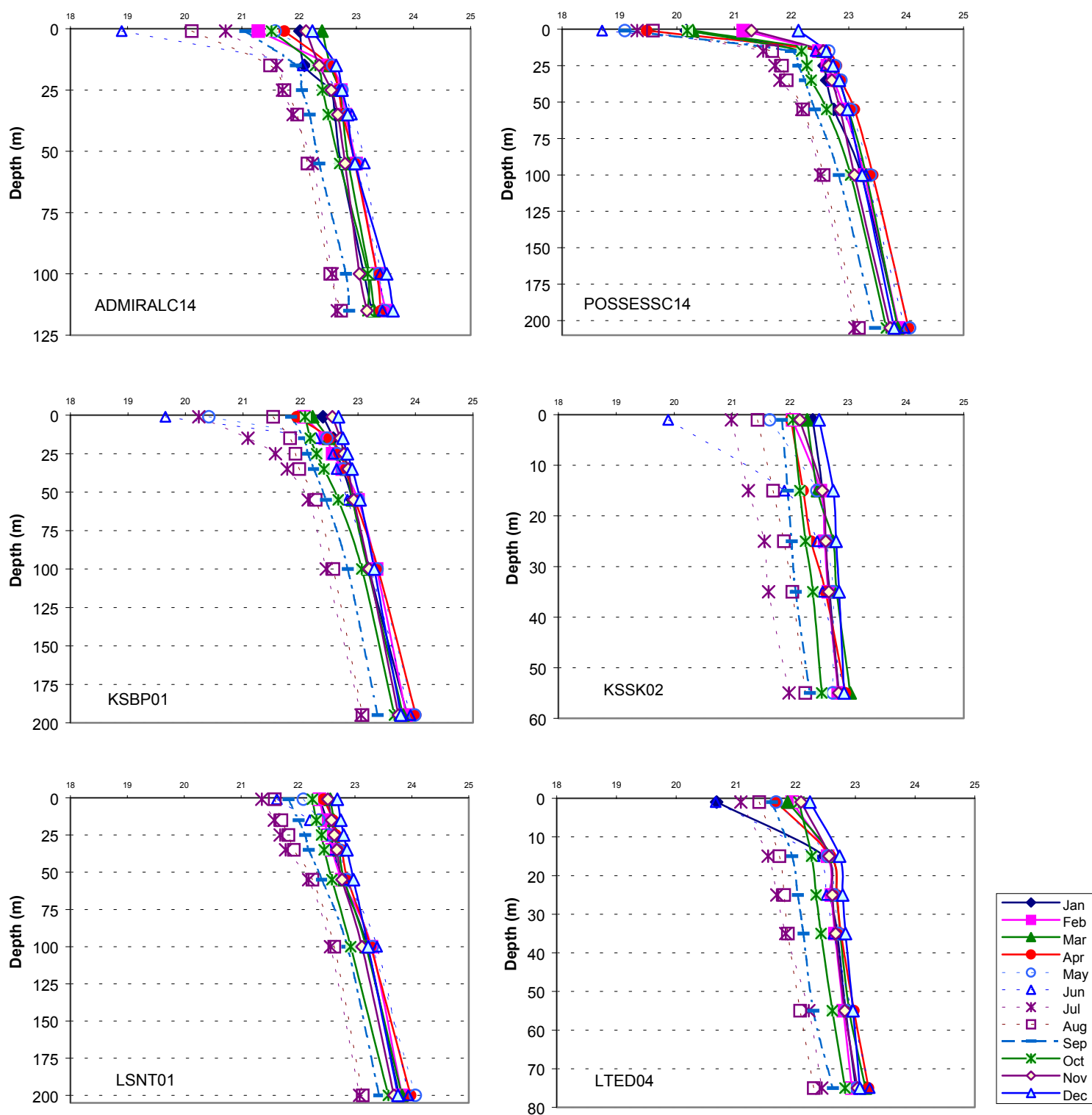


Figure 3-14. Density (σ_t) at Six Stations in 2000

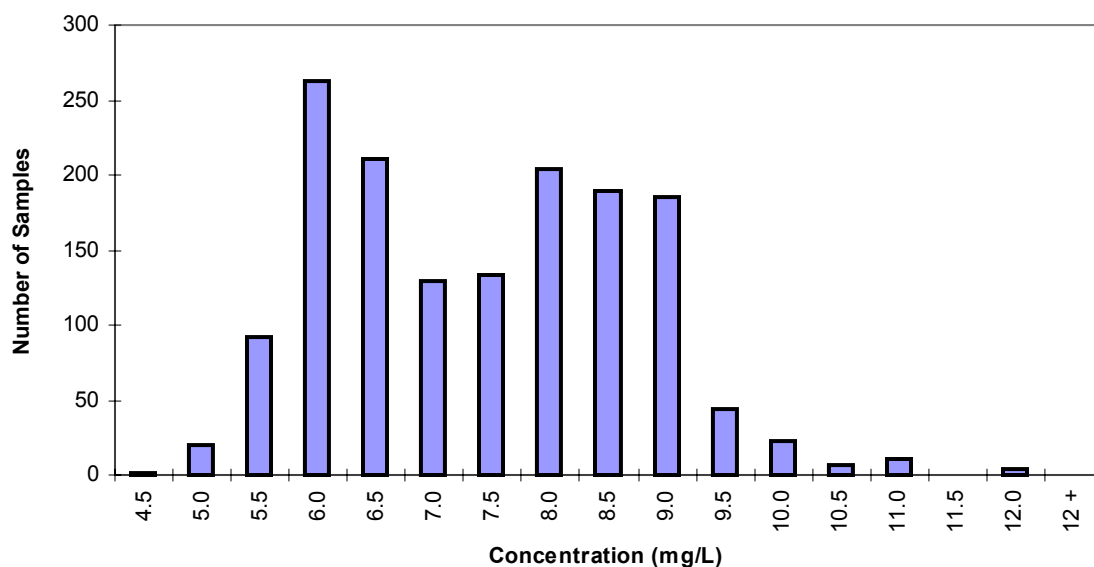


Figure 3-15. Dissolved Oxygen (mg/L) at Offshore Stations in 1999 and 2000

Most dissolved oxygen values were below 7.0 mg/L from August to November in both 1999 and 2000 for all depths and stations. Dissolved oxygen concentrations below 7.0 mg/L occur naturally during late summer and fall due to the input of deep oceanic water which contains low amounts of dissolved oxygen. During the summer months, surface water oxygen concentrations are greater than 7.0 mg/L, however, concentrations decrease with increasing depth. This is due to warmer water temperatures which contain less oxygen and no photosynthesis occurs at these depths. Overall, station LTED04 in inner Elliott Bay had the lowest values throughout the year (mean = 7.0 mg/L) for both 1999 and 2000. Station LSKQ06 near Alki Point and the Admiralty Inlet station had the highest overall values in 1999 and 2000, with averages of 7.5 and 7.4 mg/L, respectively.

Washington State marine surface water quality standards for dissolved oxygen vary depending upon the intended water use. The Class AA and Class A standards for dissolved oxygen state that concentrations should be above 7.0 and 6.0 mg/L, respectively, but acknowledge that natural conditions in the Sound can cause concentrations to fall below these standards. When seasonally low dissolved oxygen concentrations occur, human activities should not cause oxygen levels to drop by more than 0.2 mg/L. Ecology uses a dissolved oxygen concentration of 5.0 mg/L as a guideline to indicate where potential problems could occur (Ecology, 1998). Concentrations in both 1999 and 2000 were above 5.0 mg/L for all but three stations: LSNT01, LTED04, and POSSESSC14. At the 200 m depth for station LSNT01, located in the mid-channel of the Main Basin, dissolved oxygen concentrations were 4.9 mg/L in August of 1999 and 2000.

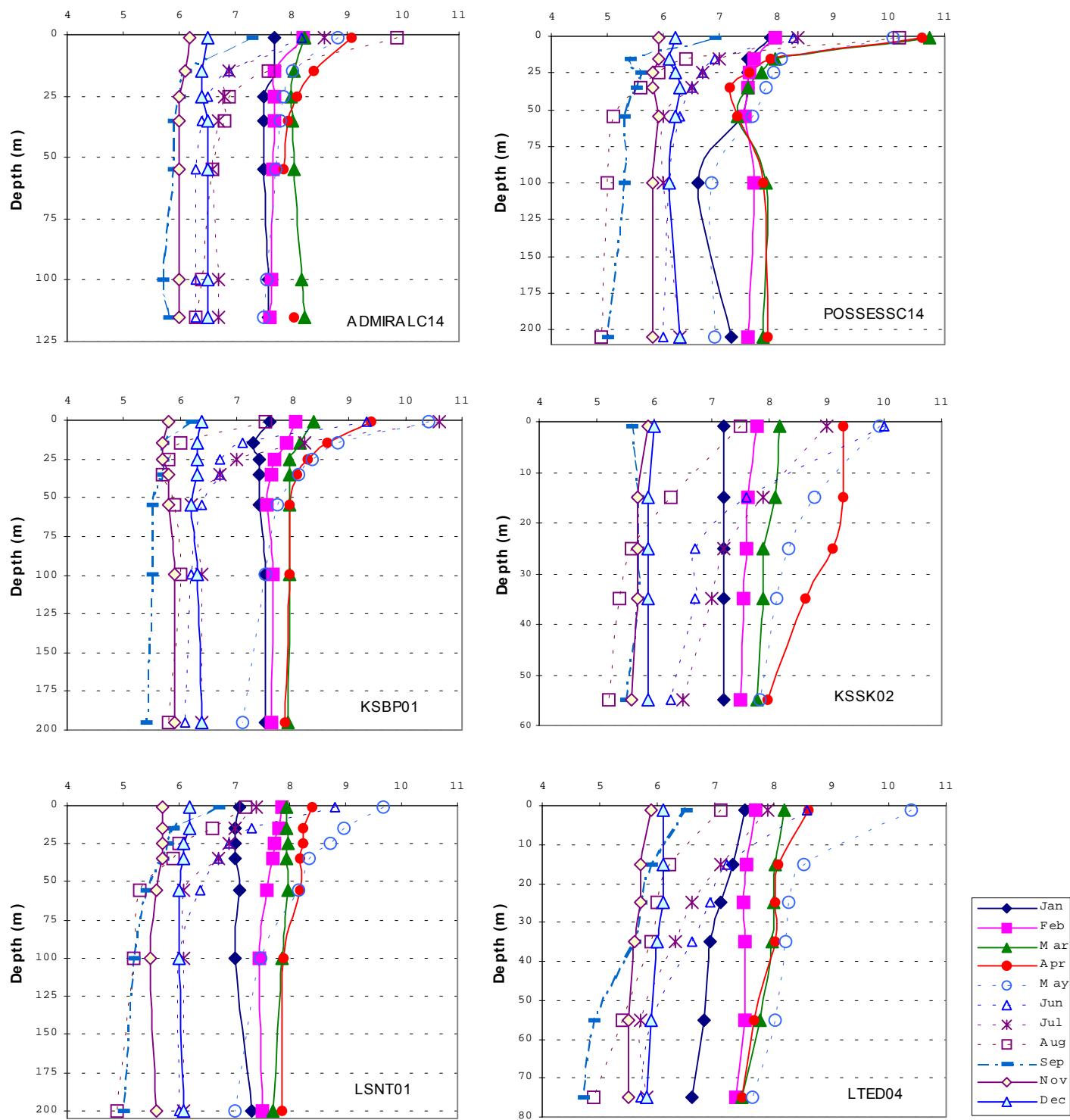


Figure 3-16. Dissolved Oxygen (mg/L) at Six Stations in 2000

Concentrations at other depths and times of the year were above 5.0 mg/L. Station LTED04 had concentrations between 4.5 and 4.9 mg/L at the deepest sampling depths in September 1999 and August and September 2000. The Possession Sound station had a value of 4.9 mg/L at the deepest sampling depth (205 m) in August 1999 and 2000. A value of 4.8 mg/L was measured at the 15 m depth in October 1999. Concentrations at other depths in October 1999 ranged from 5.0 to 5.5 mg/L, indicating the presence of upwelled water in Possession Sound.

3.2.5 Transparency and Light Intensity

Secchi disk (transparency) measurements provide an indication of water clarity and the higher the value, the clearer the water. Secchi disk values ranged from 1.0 to 21.5 m for all stations in 1999 and 2000. The lowest values were observed in May and June when phytoplankton concentrations were elevated. For all stations, transparencies were higher in the fall and winter months with October having the highest values. August 2000 values were high (10.0 to 21.5 m) at most stations except the northern Admiralty Inlet and Possession Sound stations, which can be affected by wind, waves, and freshwater input more than other stations. Stations that are located in the central portion of the Main Basin, such as KSBP01 and LSNT01, tended to have higher values than those stations located closer to shore.

Turbidity

Turbidity is also a measure of water clarity but differs from Secchi disk measurement in that it is an expression of the water's optical property that causes light to be scattered and absorbed. Both suspended and dissolved solids (including detritus, plankton, and particulates), wind, and waves can affect the water's optical properties resulting in high turbidity values. The lower the value, the clearer the water. In both 1999 and 2000, turbidity values ranged from 0.02 to 6.9 FTU. The highest values were seen at the surface and at the bottom depth at each station. January had the highest values and April the lowest. Turbidity values averaged throughout the year and at all depths for all stations were similar with values ranging from 1.34 (West Point) to 1.73 (Point Wells) FTU.

Photosynthetically Active Radiation

Photosynthetically active radiation (PAR), also expressed as light intensity, is a measure of the amount of light which is available to macrophytes and phytoplankton for photosynthesis. Only wavelengths that plants use for photosynthesis (from 400 to 700 nanometers) are measured for this parameter. Light intensity values for both 1999 and 2000 ranged from 0.05 to 2880 $\mu\text{mol}/\text{sm}^2$, with the highest single value measured at station LSKQ06 (Alki) in July 1999. Light levels drop rapidly with increasing depth as shown in Table 3-3. Percentage of light at the surface at 1 m was 83.5% for all stations compared to a level of only 0.1% at 35 m. The data for both years suggest that there is little light available for plants at 35 m and most photosynthesis occurs between the surface and 25 m.

Table 3-3. Light Levels at Depth

Depth (m)	% of surface
1	83.54
15	2.80
25	0.47
35	0.10
55	0.02
100	0.02
200	0.02

Only slight variations were noted for both years and all stations. When only surface down to 25 m data are compared for each site, the Colvos Passage station had the highest overall values for both years and stations from Point Jefferson to southern Possession Sound (KSBP01, PtWells1, and POSSESSC14) had the lowest. January had the highest light levels penetrating at all depths and also if only the surface to 25 m depths are compared. October had the lowest values for both years.

3.2.6 Nutrients

Nitrogen compounds

Several forms of inorganic nitrogen are commonly found in the marine environment. These compounds include ammonia, nitrate, and nitrite, with nitrate being the primary form of inorganic nitrogen in seawater. The analytical method used by the King County Environmental Laboratory to measure nitrate concentrations does not distinguish between nitrate and nitrite, therefore, these two forms are reported as one value expressed as nitrate+nitrite. Nitrite concentrations in the water column are naturally very low and the contribution of nitrite to the total value is usually minimal. Values for ammonia and nitrate+nitrite are reported below.

Ammonia. Values at all offshore stations in 1999 and 2000 ranged from less than the MDL (0.01) to 0.39 mg/L. The mean concentration for all stations for both years was 0.02 mg/L, which is similar to past results. Most ammonia concentrations monitored at all depths were at or below the MDL from November to March in 1999 and between October and February in 2000. Higher ammonia concentrations during the summer months are common as ammonia is generated from the decay of organic nitrogen (both natural and from zooplankton grazing on phytoplankton) and peaks about the time of senescence (decay) in the producer growth cycle (Valiela, 1984). The highest concentration was detected at station KSSK02 in September 2000, when the highest chlorophyll concentration was also measured indicating the presence of a phytoplankton bloom. Figure 3-17

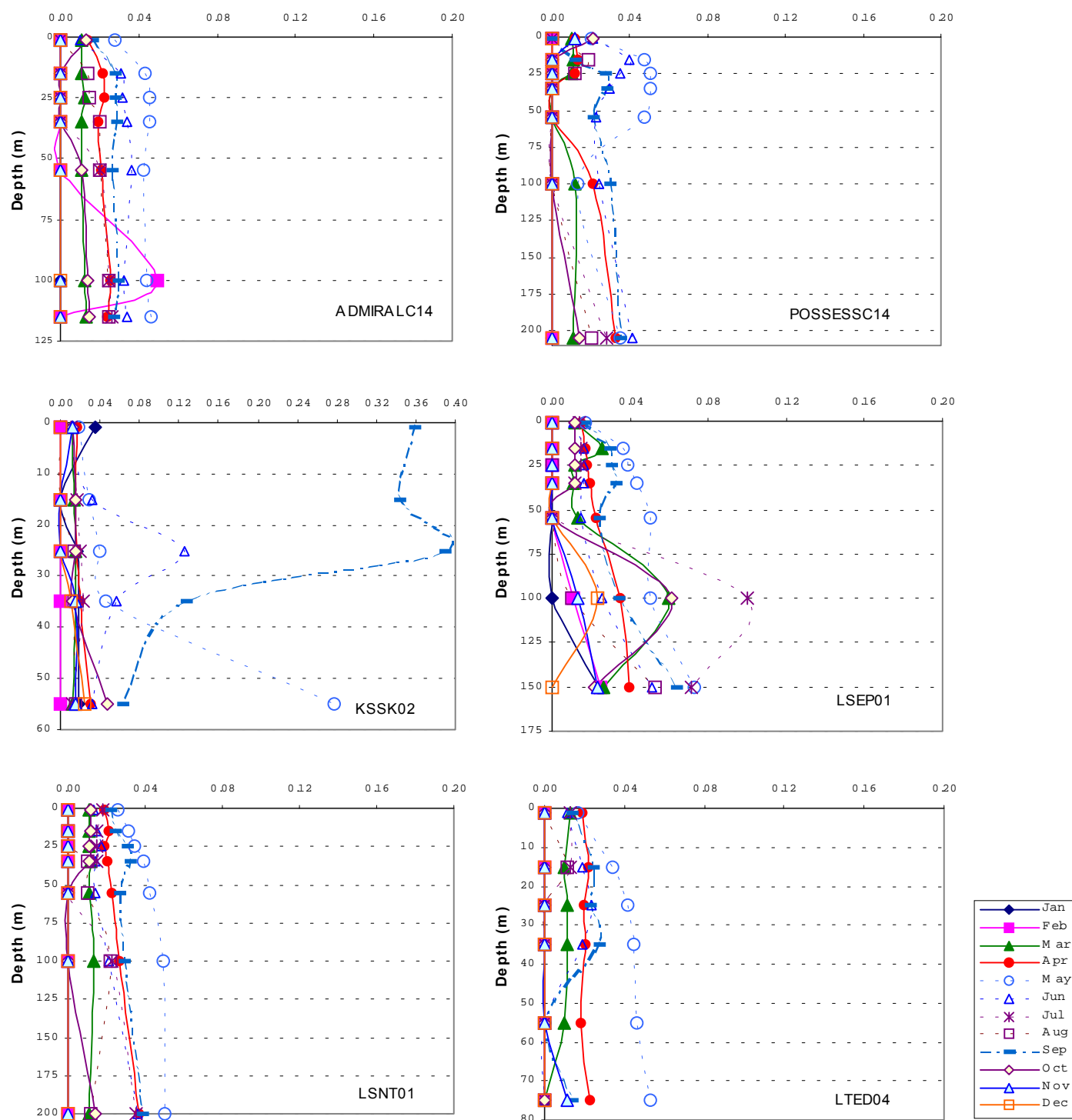


Figure 3-17. Ammonia (mg/L) Concentrations at Six Stations in 2000

shows ammonia concentrations for six offshore stations. The plots show concentrations at the northern stations (Admiralty Inlet and Possession Sound) were similar to concentrations measured at most of the more southern stations. All stations except KSSK02 (West Point outfall), LSEP01 (South Plant outfall), and PtWells1 (Point Wells), had a mean value of 0.01 mg/L for both years combined. The mean value at station KSSK02 was 0.04 mg/L and LSEP01 and PtWells1 were 0.02 mg/L for both years combined.

Washington State ammonia criteria for marine surface waters are based upon un-ionized ammonia. However, for total ammonia (measured by King County) the State uses U.S. EPA's criteria concentrations which are based upon total ammonia. These total ammonia criteria are based on temperature, salinity, and pH of the water. Using a temperature of 15 °C, a salinity of 30 pss, and a pH of 8.0--all ammonia concentrations measured for offshore stations were well below the 1.6 mg/L chronic criterion.

Ammonia concentrations at all beach stations in 1999 and 2000 ranged from less than the MDL (0.01) to 0.11 mg/L. The mean concentration for all stations for both years was 0.02 mg/L, which is similar to the offshore station results. Station LSVW01 in Fauntleroy Cove had the highest concentration measured in September 2000. Excluding this 0.11 mg/L value, all maximum values measured at the other stations ranged from 0.03 to 0.07 mg/L. Figure 3-18 shows the maximum, mean, and median concentrations for the majority of the beach stations. Seven of the 24 beach stations were added in 2000, therefore, mean concentrations for these 7 stations do not include 1999 data. For the stations that were monitored in both 1999 and 2000, concentrations were similar for both years. The highest overall concentrations were measured in September and May with the lowest concentrations occurring between November to April. The seasonal pattern observed for the beach stations is similar to that seen for the offshore stations. As with the offshore stations, concentrations measured for beach stations were well below the 1.6 mg/L chronic criterion.

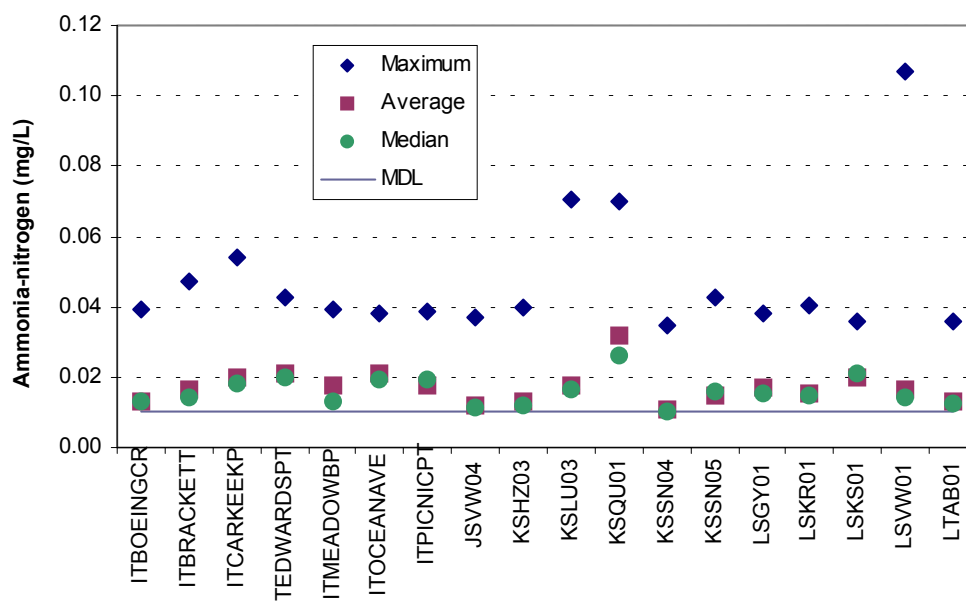


Figure 3-18. Ammonia Concentrations at Beach Stations in 1999 and 2000

Nitrate+Nitrite. For offshore stations, nitrate+nitrite concentrations ranged from less than the MDL (0.02) to 0.48 mg/L for both years monitored. Concentrations were similar for both years and were also similar to values measured in previous years. Figure 3-19 shows nitrate+nitrite concentrations measured in 2000 for six stations. The pattern for other stations is similar to those shown in Figure 3-19. As stated above, nitrate is usually the primary form of inorganic nitrogen in seawater and was most abundant in the winter (from November to February) when it was not taken up by phytoplankton and when freshwater runoff was highest. The lowest concentrations were measured between May and July (Figure 3-20). Values below the detection limit only occurred near the surface in the spring and summer months when phytoplankton blooms were evident. Phytoplankton uptake is restricted to the photic zone (the zone where enough light penetrates for photosynthesis to occur) which is the reason nitrate+nitrite concentrations tend to increase at depth during the summer months. Average concentrations for both years at depths between 35 and 200 m were 0.33 mg/L and average concentrations from depths between 1 and 25 m were slightly lower ranging from 0.27 (at the surface) to 0.32 mg/L. All offshore stations had similar concentrations with average values for both years ranging from 0.30 to 0.33 mg/L.

Nitrate+nitrite values at all beach stations in 1999 and 2000 ranged from less than the MDL (0.02) to 0.81 mg/L. The mean concentration for all stations for both years was 0.25 mg/L. Concentrations were similar for both years with average concentrations for all stations at 0.26 and 0.25 mg/L, respectively, for 1999 and 2000. However, the MOSS beach stations were only sampled beginning in March 2000. Nutrients have not been measured at beach stations previously, therefore, comparisons with past monitoring results are not possible. Station KSHZ03 near Carkeek Park had the highest concentration measured in January 1999. Station KSHZ03 also had the highest average concentration for both years (0.32 mg/L) of all the stations sampled. As observed at offshore stations, the highest nitrate+nitrite concentrations were in the winter months from November to March, with average concentrations during these months ranging from 0.37 to 0.43 mg/L. The lowest average concentrations were from May to August ranging between 0.06 to 0.17 mg/L, with the lowest concentration observed in June.

Total Phosphorus

Phosphorus is found as dissolved inorganic, dissolved organic, and particulate phosphorus in seawater. Generally, particulate phosphorus is the most abundant form. Several forms of inorganic phosphorus are found in the marine environment. The most abundant forms of phosphorus are the orthophosphate ions, with HPO_4^{2-} being the major ion in seawater (Valiela, 1984). Total phosphorus, which includes all forms of inorganic and organic phosphorus, is measured by the King County Environmental Laboratory.

For all offshore stations and depths, values ranged between 0.03 and 0.11 mg/L, with a mean concentration of 0.07 mg/L. Concentrations were similar for both years, with both 1999 and 2000 results having a mean concentration of 0.07 mg/L. This mean is similar to past results. The highest concentration was measured at the surface at station KSSK02 (West Point) in September 2000. This station also had the highest ammonia concentration measured at this time, but not the highest nitrate+nitrite concentration. There was little variation with depth, with mean

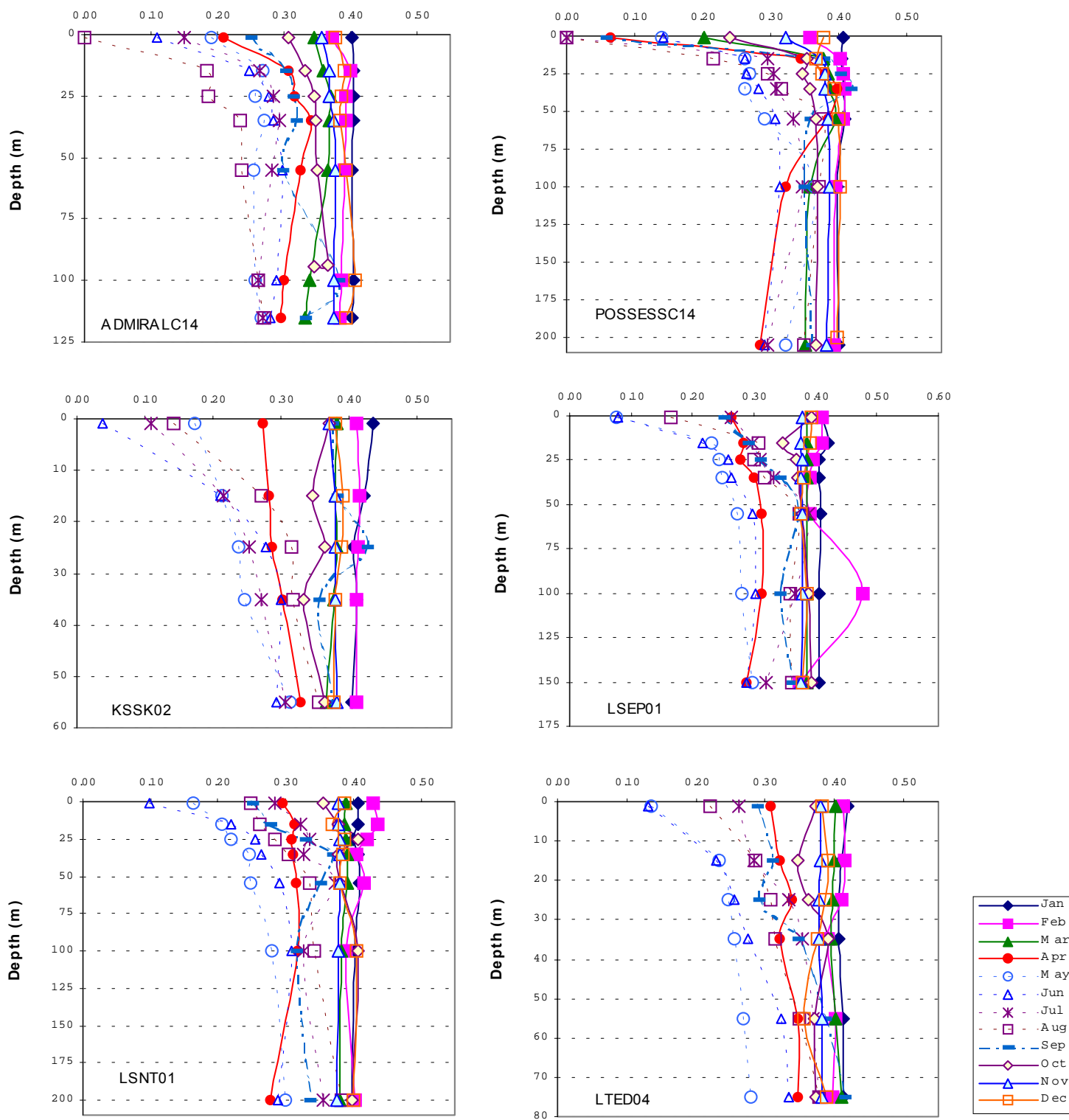


Figure 3-19. Nitrate+Nitrite (mg/L) Concentrations at Six Stations in 2000

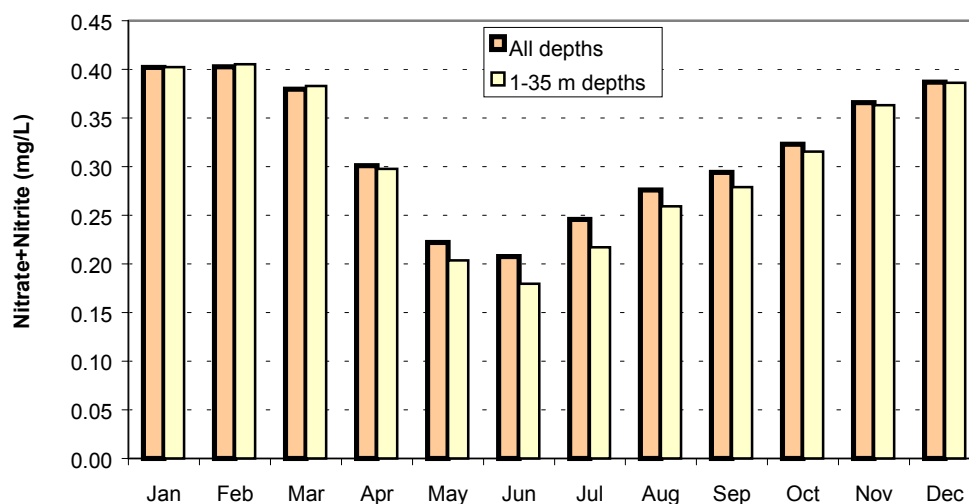


Figure 3-20. Monthly Nitrate+Nitrite Concentrations for All Offshore Stations

concentrations ranging between 0.06 (surface) to 0.09 (100 m) mg/L. Although a trend with respect to depth was not evident, results do show a clear seasonal trend with levels decreasing at the surface depths during the summer months, due to phytoplankton uptake. Mean concentrations for depths within the photic zone (1 to 35 m) were lowest between May and July (0.05 mg/L) and highest between December and February (0.08 mg/L). This trend was also observed for other nutrients, such as nitrate+nitrite and ammonia.

Total phosphorus values for all beach stations in 1999 and 2000 ranged between 0.02 to 0.79 mg/L, with a mean concentration of 0.08 mg/L. Mean concentrations for the beach stations are similar to those measured for offshore stations, however, maximum concentrations are higher for the beach stations. Station KSSN05 on the south side of West Point had the highest concentrations in December and February 1999 (0.79 and 0.78 mg/L, respectively), with the next highest concentration also measured in December 1999 at station LSVW01 (0.48 mg/L) in Fauntleroy Cove. Station KSSN05 also had the highest mean concentration of the beach stations monitored (0.20 mg/L) with mean concentrations at all other stations ranging between 0.05 (KSQU01) and 0.09 (LSVW01 and LSKS01) mg/L. However, as noted above the MOSS beach stations were only sampled starting in March 2000. The same seasonal trend that was observed at offshore stations was also evident for the beach stations, with lower concentrations between May and July and higher concentrations observed in the winter months.

Silica

Silica concentrations for all offshore stations monitored in 1999 and 2000 ranged from 0.27 to 5.23 mg/L, with a mean concentration of 2.75 mg/L. Concentrations were similar between both years with a mean concentration in 1999 of 2.54 mg/L and a mean in 2000 of 2.95 mg/L. Silica

concentrations were lower at the surface depths in the summer months as diatoms (microscopic photosynthetic plants) use silica for skeletal growth and tend to concentrate at the surface. Figure 3-21 shows the mean, maximum, and minimum silica concentrations measured by depth at all offshore stations in 1999 and 2000. Overall, the lowest concentrations were seen from June to September when phytoplankton abundance was high, with June having the lowest concentrations in both 1999 and 2000. Nitrate+nitrite concentrations were also the lowest in June from phytoplankton uptake. Highest concentrations occurred between December and March, particularly in February when biological uptake is low and freshwater runoff is high. The highest concentrations occurred at the two inner Elliott Bay stations, LTED04 and LTBC41, which are influenced by particulates from the Duwamish River. Higher silica concentrations have also been seen in past years at these two stations. Although maximum concentrations were higher at the Elliott Bay stations during some months, mean concentrations for all offshore stations throughout both years were similar with values ranging from 2.59 mg/L (station ADMIRALC14) to 2.87 mg/L (station LTED04). Figure 3-22 shows the silica patterns for six stations sampled in 2000, which are representative of the patterns seen at other stations.

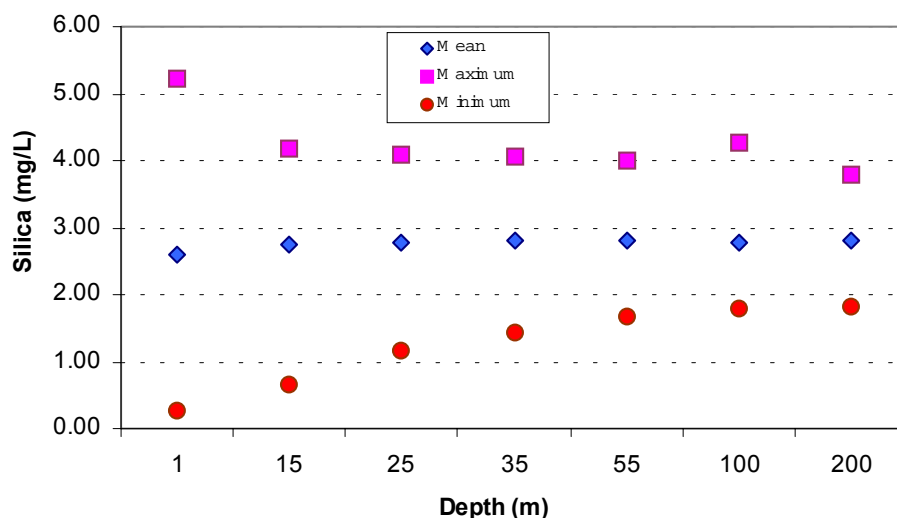


Figure 3-21. Silica Concentrations at All Offshore Stations in 1999 and 2000

Silica concentrations at beach stations were slightly higher than those at offshore stations with values ranging from 0.54 to 10.60 mg/L and a mean concentration for all stations in both 1999 and 2000 of 3.07 mg/L. Beach stations receive more influence from freshwater runoff and from suspension of silica attached to particulates than the offshore stations. Concentrations were similar between both years although the MOSS stations were only sampled in 2000, with mean concentrations of 3.00 and 3.12 mg/L in 1999 and 2000, respectively. Station KSHZ03, located near the mouth of Piper's Creek at Carkeek Park, had the highest silica concentration (10.60 mg/L) in October 2000. Station ITCARKEEKP, which is located outside the influence of Piper's Creek but near Carkeek Park, had a concentration of 3.24 mg/L during that same month indicating the high concentration at KSHZ03 is due to particulates from Piper's Creek. Station

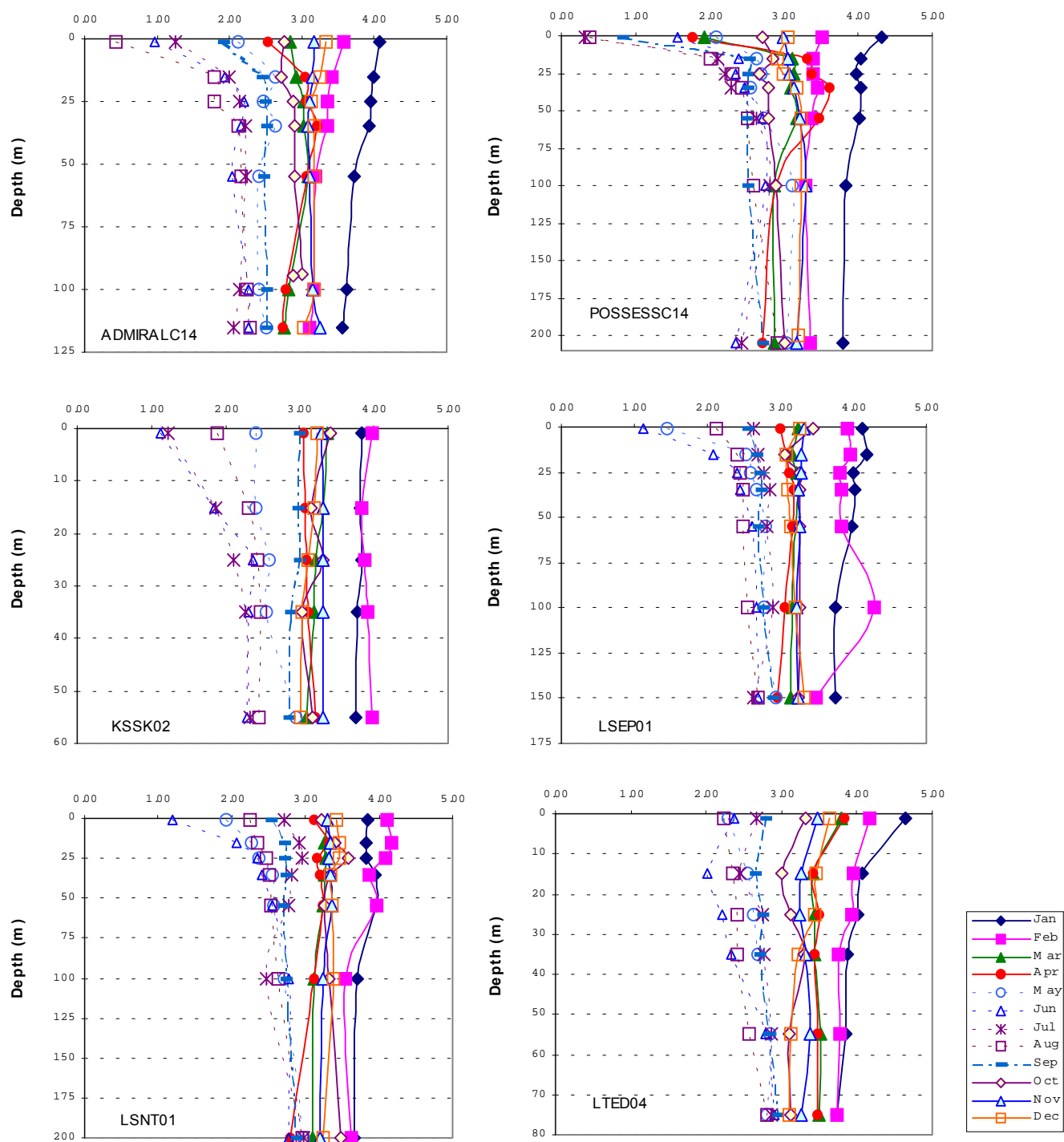


Figure 3-22. Silica (mg/L) Concentrations at Six Stations in 2000

KSHZ03 also had the highest mean concentration (4.41 mg/L) and the Brackett's Landing station had the lowest at 2.29 mg/L. Station LSVW01 located in Fauntleroy Cove, where there are several small storm drain pipes and where Fauntleroy Creek enters the Sound, had a mean concentration of 3.92 mg/L and station KSQU01, influenced by the Lake Washington Ship Canal, had a mean concentration of 3.89 mg/L. Figure 3-23 shows the maximum, mean, and median concentrations for the majority of the beach stations in 1999 and 2000. Concentrations for MOSS stations only include 2000 data. Beach stations showed the same seasonal pattern as the offshore stations with highest concentrations from December to March and lower concentrations from May to September, with June having the lowest concentrations for both years.

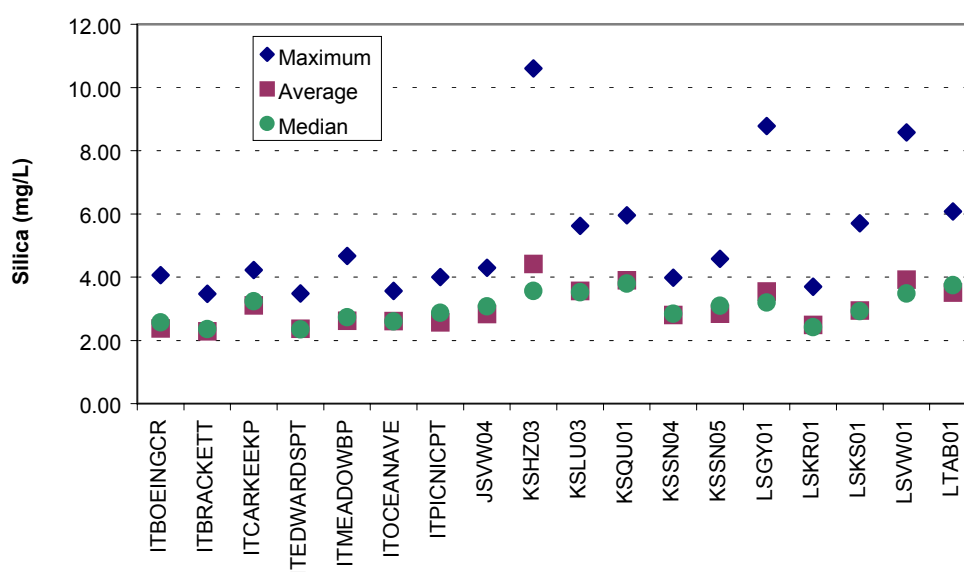


Figure 3-23. Silica Concentrations at Beach Stations in 1999 and 2000

3.2.7 Chlorophyll-*a* and Pheophytin

Both chlorophyll-*a* and pheophytin were measured in 1999 and 2000 at all offshore stations from the surface down to a depth of 35 m. Chlorophyll and pheophytin were not measured for beach stations. Chlorophyll-*a* values for both 1999 and 2000 ranged from 0.03 to 34.80 µg/L with a mean concentration of 2.28 µg/L. Pheophytin values for both 1999 and 2000 ranged from less than the MDL (0.01 µg/L) to 4.00 µg/L, with a mean concentration of 0.49 µg/L. Concentrations were similar for both years with mean chlorophyll-*a* and pheophytin concentrations in 1999 of 2.01 and 0.50 µg/L and means of 2.52 and 0.49 µg/L in 2000, respectively. Both chlorophyll-*a*

and pheophytin levels were low in the winter months and decreased with depth. This decrease with depth corresponds to the decreased light availability for plant growth in deeper water. As seen with nutrient concentrations, chlorophyll-*a* concentrations were the lowest from November to February and the highest from May to September. Chlorophyll-*a* values for six stations sampled in 1999 and 2000 are shown in Figures 3-24 and 3-25 and are representative of the other stations sampled. Plots for both years are provided to show when phytoplankton blooms occurred. The highest chlorophyll-*a* surface value was seen at station LTBC41 in inner Elliott Bay in September 1999. Station KSBP01 had the highest mean concentration for both years combined (3.07 µg/L) and one of the inner Elliott Bay stations (LTED04) had the lowest mean concentration at 1.41 µg/L. Although maximum concentrations vary from year to year, phytoplankton blooms (as indicated by high chlorophyll-*a* levels) exhibit seasonal trends with blooms usually occurring in April or May and July. Phytoplankton blooms in 1999 and 2000 were not as consistent as seen in previous years with high chlorophyll-*a* concentrations at some stations but not others and at differing times of the year. In 1999, chlorophyll-*a* values were elevated in May, June, and September at most stations, with a large phytoplankton bloom indicated in September. The Admiralty Inlet station (ADMIRALC14) also had high chlorophyll-*a* in July and particularly in October (24.7 µg/L)—which is the latest month in which a bloom has been seen. This station is a MOSS site and had not been sampled prior to 1999, therefore, it is possible that an October bloom is a typical occurrence at this station although none was observed in 2000. The Possession Sound station (POSSESSC14) had high chlorophyll-*a* values in April which were not seen at any other station but did not exhibit a bloom in June or July. In 2000, chlorophyll-*a* values were elevated in May, June, and August at all stations. The three northernmost stations (ADMIRALC14, POSSESSC14, and KSBP01) also exhibited high concentrations in April that were not seen at any of the other stations. The Possession Sound station also had high chlorophyll-*a* levels in March which was not seen at other stations. In 1997, phytoplankton blooms were observed as late as September but in both 1996 and 1998, the latest blooms occurred in July. Although the May and June blooms appears to be relatively consistent for both 1999 and 2000, the timing of the late summer/early fall bloom was variable.

Several factors influence chlorophyll concentrations, including availability of light and nutrients, air temperature, wind, and zooplankton grazing. As noted in the previous chapter, pheopigments, such as pheophytin, are degradation products of chlorophyll produced when zooplankton graze on phytoplankton cells. For both years, pheophytin values were higher at the surface and decreased with depth. When chlorophyll concentrations were high, pheophytin concentrations were also high. The months when mean pheophytin values were at their highest, May (1.12 µg/L), June (1.12 µg/L), and September (0.73 µg/L), were also the months when phytoplankton blooms were indicated. The lowest values occurred between November and January.

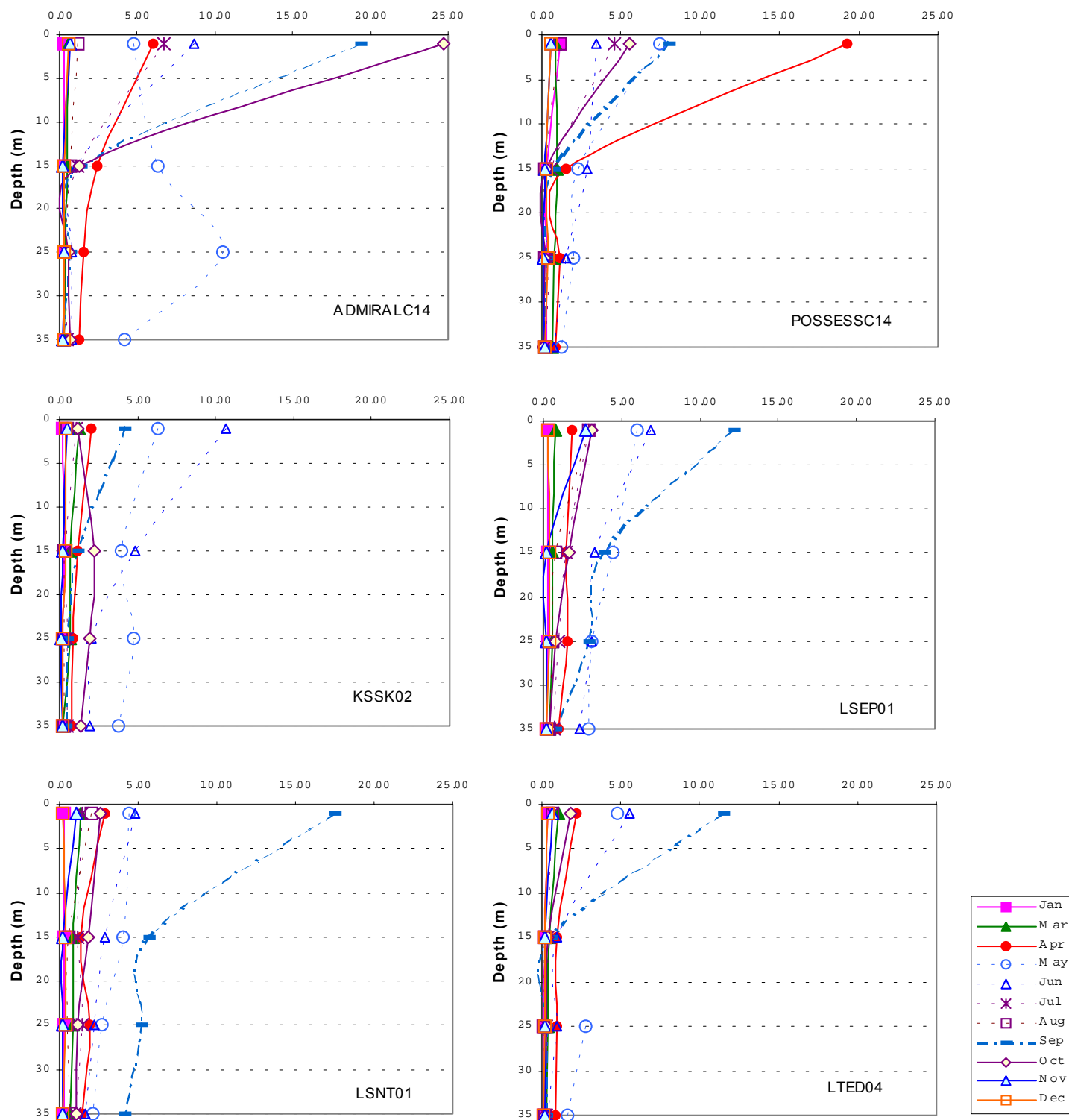


Figure 3-24. Chlorophyll-a ($\mu\text{g/L}$) Concentrations at Six Stations in 1999

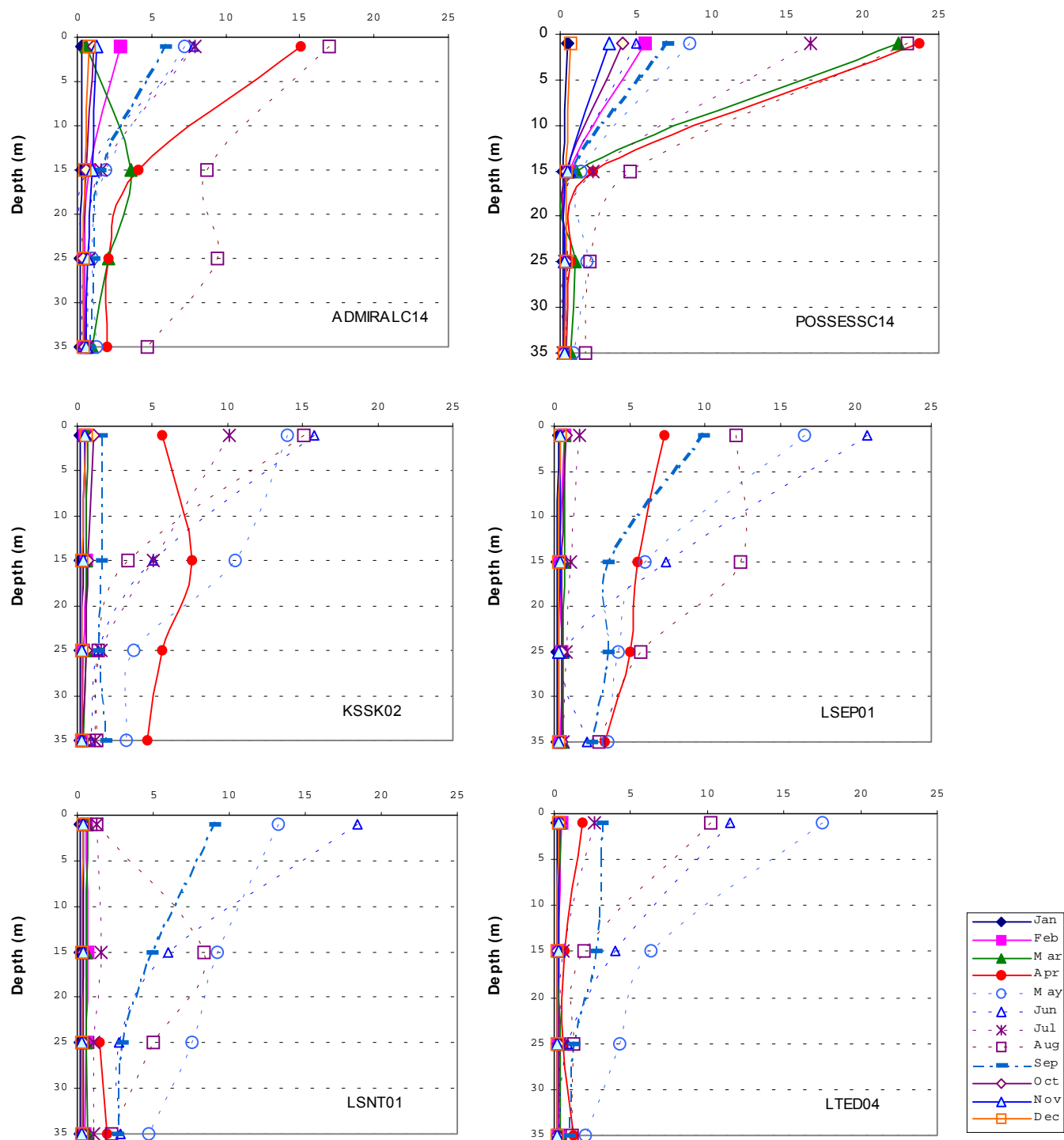


Figure 3-25. Chlorophyll-a (µg/L) Concentrations at Six Stations in 2000

3.2.8 Water Column Metals

Monthly water column samples were collected from eight offshore stations between April 1999 and June 2000 for analysis of trace metals. Samples were collected from three depths at each of the stations noted below.

- Admiralty Inlet (ADMIRALC14) – 5, 50, and 110 meters
- Possession Sound (POSSESSC14) – 5, 50, and 190 meters
- Point Wells (PTWELLS1) – 5, 50, and 120 meters
- Jefferson Head (KSBP01) – 5, 50, and 210 meters
- West Point Outfall (KSSK02) – 5, 30, and 55 meters
- Renton Outfall (LSEP01) – 5, 50, and 130 meters
- Fauntleroy/Vashon (LSNT01) – 5, 50, and 170 meters
- Colvos Passage (COLVOSPASS) – 5, 50, and 85 meters

The samples were analyzed for the following elements, both the total and dissolved fractions: antimony, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc. Analyses of all metals, with the exception of mercury, were performed by the King County Environmental Laboratory. Frontier Geosciences of Seattle, Washington performed the total and dissolved mercury analysis.

Water Column Total Metals

Reportable concentrations of 8 of the 14 total metals (arsenic, cadmium, chromium, copper, mercury, nickel, thallium, and vanadium) were detected in all samples. Another four metals (antimony, cobalt, lead, and zinc) were detected in greater than 90% of the samples. Selenium and silver were never detected.

It should be noted that antimony, cobalt, lead, and zinc were actually detected in all of the samples, however, data validation determined that some analytical results were impacted by quality control failures that indicated probable laboratory contamination. Although care was taken during analysis to minimize sample contamination, these four metals were occasionally detected in analytical method blanks.

A method blank is a negative control sample that indicates probable laboratory contamination when an analytical result for any element is greater than the method detection limit. When any metal was detected in a method blank, associated sample data for that metal were flagged “B” if the reported sample concentrations were less than five times the concentration detected in the method blank. For purposes of this report, those data points flagged “B” were considered undetected.

Table 3-4 summarizes water column total metals data, providing frequency of detection and minimum, maximum, and mean concentrations. Complete water column total metals data may be found in Appendix A.

Table 3-4 Total Metals Detected in Offshore Water Column Samples
Frequency of Detection and Minimum, Maximum, and Mean Concentrations (µg/L)

Metal	FOD %	Minimum	Maximum	Mean
Antimony	97	0.030	0.116	0.077
Arsenic	100	0.81	1.44	1.11
Cadmium	100	0.0499	0.0926	0.0662
Chromium	100	0.110	0.451	0.194
Cobalt	97	0.015	0.104	0.030
Copper	100	0.294	0.978	0.420
Lead	98	0.008	0.163	0.026
Mercury	100	0.00014	0.00199	0.00034
Nickel	100	0.376	0.683	0.451
Thallium	100	0.008	0.014	0.011
Vanadium	100	1.01	1.76	1.40
Zinc	94	0.25	1.21	0.51

Quality control field blanks collected during each trace metals sampling event included atmosphere, carboy, equipment, tubing, and sampling blanks. These field blanks were analyzed along with other samples as part of the overall quality assurance plan to provide an indication of possible contamination during sample collection. Most metals were not detected, or detected rarely, in field blanks. Mercury, however, was detected in almost every field blank at concentrations similar to water column samples.

Water Column Dissolved Metals

Reportable concentrations of four of the 14 dissolved metals (arsenic, cadmium, thallium, and vanadium) were detected in all of the samples. Another five metals (antimony, cobalt, copper, mercury, and nickel) were detected in greater than 90% of the samples. Chromium, lead, and zinc were detected less frequently in the dissolved fraction. Selenium and silver were never detected.

Antimony, chromium, cobalt, copper, mercury, nickel, and zinc were actually detected in all of the samples, however, data validation determined again that some analytical results were impacted by quality control failures that indicated probable laboratory contamination. Zinc was especially problematic; approximately 65% of the samples were impacted by method blank contamination. Again, for purposes of this report, those data points flagged “B” were considered undetected. There were also a few method blanks with positive results for lead, however, the low frequency of detection for lead is mainly attributed to its absence in the environment at detectable levels for the dissolved fraction.

Table 3-5 summarizes water column dissolved metals data, providing frequency of detection and minimum, maximum, and mean concentrations. Complete water column dissolved metals data may be found in Appendix A.

Table 3-5. Dissolved Metals Detected in Offshore Water Column Samples
Frequency of Detection and Minimum, Maximum, and Mean Concentrations (µg/L)

Metal	FOD %	Minimum	Maximum	Mean
Antimony	94	0.027	0.134	0.083
Arsenic	100	0.86	1.37	1.12
Cadmium	100	0.0346	0.0773	0.0634
Chromium	82	0.045	0.363	0.128
Cobalt	93	0.0071	0.0498	0.0201
Copper	93	0.255	0.573	0.348
Lead	29	0.0049	0.0309	0.0068
Mercury	94	0.00010	0.00064	0.00020
Nickel	91	0.357	0.660	0.414
Thallium	100	0.008	0.013	0.010
Vanadium	100	1.07	1.55	1.37
Zinc	35	0.24	1.79	0.64

Statistical Analysis of Water Column Metals Data

The water column metals data collected during this field effort are not symmetrically distributed, with small coefficients of variation in their log transforms. With the exception of selenium and silver, the data collected are sufficient to characterize the mean (sensitive to within 50%) for each metal, at each site and depth, with a minimum power of 85% and a significance level of 90%. The sample size for this data set is also sufficient to perform three-way ANOVA analyses for all the metals to compare mean values between all eight sites and three sampling depths.

A separate report on metal concentrations in the water column will be published at a later date and will include an analysis of spatial and temporal variations. Therefore, statistical analyses will not be presented in this report.

Washington State Water Quality Criteria for Trace Metals

Washington state has promulgated water quality criteria for nine of the 14 metals analyzed during this sampling effort. Table 3-6 summarizes water column trace metals analytical results and compares them to acute and chronic water quality criteria. For most of the metals, the criteria are compared to dissolved metals. The exceptions are: mercury, for which the chronic criterion is for the total fraction; and zinc, for which repeated quality control failures rendered dissolved data unusable.

Table 3-6. Puget Sound Offshore Water Column Metals Concentrations Compared to Published Water Quality Criteria

Dissolved Metal ^a	Concentration (µg/L)			Marine Water Quality Criteria ^b	
	Minimum	Maximum	Mean	Acute (µg/L)	Chronic (µg/L)
Antimony	0.027	0.134	0.083	*	*
Arsenic	0.86	1.37	1.12	69.0	36.0
Cadmium	0.0346	0.0773	0.0634	42.0	9.3
Chromium	<0.04 (MDL)	0.36	0.13	*	*
Cobalt	0.007	0.050	0.020	*	*
Copper	0.255	0.573	0.348	4.8	3.1
Lead	<0.005 (MDL)	0.031	0.007	210.0	8.1
Mercury ^c	0.00014	0.00199	0.00034	1.8	0.025 ^d
Nickel	0.357	0.660	0.414	74.0	8.2
Selenium	<0.15 (MDL)	<0.15 (MDL)	<0.15 (MDL)	290	71.0
Silver	<0.06 (MDL)	<0.06 (MDL)	<0.06 (MDL)	1.9	*
Thallium	0.008	0.013	0.010	*	*
Vanadium	1.07	1.55	1.37	*	*
Zinc ^e	0.25	1.21	0.51	95 ^d	86 ^d

^a Dissolved concentrations reported for all metals except mercury and zinc.

^b Water quality criteria from Chapter 173-201A WAC (Ecology, November 1997). Criteria are for dissolved metals except as noted.

^c Total mercury concentrations reported for comparison to marine chronic criterion.

^d Criterion is for total metal.

^e Total zinc concentrations reported because of repeated quality control failures in dissolved zinc analysis.

The reported maximum concentrations for all trace metals detected in this sampling effort were well below the associated acute and chronic water quality criteria.

3.2.9 Metals in Beach Water

Beach (intertidal) water samples were collected monthly from three stations and quarterly from eight stations between March and December 2000 for analysis of metals. Samples were collected from a single depth (just below the surface) at each of the stations noted below.

- Monthly Sampling – Meadowdale Beach Park, Edwards Point, Carkeek Park
- Quarterly Sampling – Picnic Point Park, Ocean Avenue, Brackett's Landing (Underwater Park), Richmond Beach (Point Wells), Boeing Creek, North Beach (Blue Ridge Park), Golden Gardens Park, Shilshole Bay

The samples were analyzed for the following elements, both the total and dissolved fractions: antimony, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc.

In addition to the above, samples were collected annually in August 1999 and 2000 at the following sites: near Carkeek Park (different station than the monthly station), north and south side of West Point, Alki Point, Suquamish (1999 only), and Normandy Park. Samples in 1999 were analyzed for total and dissolved metals (same metals as above excluding mercury) while only dissolved metals were analyzed in 2000.

Beach Total Metals

Reportable concentrations of 10 of the 14 total metals analyzed (arsenic, cadmium, cobalt, copper, lead, mercury, nickel, thallium, vanadium, and zinc) were detected in all of the samples. Reportable concentrations of antimony and chromium were detected in 97 and 70% of the samples, respectively. Selenium and silver were never detected.

Antimony and chromium were actually detected in all of the samples, however, data validation determined that some analytical results were impacted by quality control failures that indicated probable laboratory contamination. Although care was taken during analysis to minimize sample contamination, these two metals were occasionally detected in analytical method blanks. For purposes of this report, those data points flagged “B” were considered undetected.

Table 3-7 summarizes beach water total metals data for sites sampled monthly and quarterly, providing frequency of detection and minimum, maximum, and median concentrations. Table 3-8 summarizes total metals data for the eight sites sampled annually in 1999. Complete beach water total metals data may be found in Appendix A.

Quality control for the beach water sampling program included the collection of atmosphere blanks with each sampling event. Mercury was detected in almost every atmosphere blank at concentrations similar to beach water samples.

Table 3-7. Total Metals Detected in Beach Water Samples--MOSS Area
Frequency of Detection and Minimum, Maximum, and Median Concentrations (µg/L)

Metal	FOD % (n=62)	Minimum	Maximum	Median
Antimony	97	0.028	0.089	0.067
Arsenic	100	0.77	1.29	1.01
Cadmium	100	0.0386	0.0803	0.0657
Chromium	70	0.17	5.41	0.34
Cobalt	100	0.02	1.30	0.054
Copper	100	0.383	3.120	0.573
Lead	100	0.0264	11.600	0.850
Mercury	100	0.00028	0.00508	0.00070
Nickel	100	0.420	7.500	0.962
Thallium	100	0.006	0.026	0.011
Vanadium	100	0.892	6.500	1.480
Zinc	100	0.51	8.09	1.10

Table 3-8. Total Metals Detected in Beach Water Samples at Sites Sampled Annually
Frequency of Detection and Minimum, Maximum, and Median Concentrations (µg/L)

Metal	FOD % (n=8)	Minimum	Maximum	Median
Antimony	100	0.032	0.093	0.084
Arsenic	100	0.98	1.47	1.12
Cadmium	100	0.040	0.079	0.067
Chromium	100	0.22	3.54	0.51
Cobalt	100	0.043	1.06	0.127
Copper	100	0.468	3.90	1.224
Lead	100	0.047	1.28	0.288
Nickel	100	0.448	4.83	0.885
Thallium	100	0.01	0.02	0.01
Vanadium	100	1.36	4.81	1.92
Zinc	100	0.72	27.50	5.55

Beach Dissolved Metals

At stations where samples were collected monthly and quarterly, concentrations of 7 of 14 dissolved metals (antimony, arsenic, cadmium, chromium, copper, thallium, and vanadium) were detected in all the samples. Another three dissolved metals (cobalt, mercury, and nickel) were detected in greater than 90 % of the samples. Lead and zinc were detected less frequently in the dissolved fraction. Selenium and silver were never detected.

Cobalt, mercury, nickel, and zinc were detected in all the samples, however, data validation determined that some analytical results were impacted by quality control failures that indicated

probable laboratory contamination. Zinc was especially problematic; approximately 77 % of the samples were impacted by method blank contamination. Again, for purposes of this report, those data points flagged “B” were considered undetected. There were a few method blanks with positive results for lead, however, the low frequency of detection for lead was mainly attributed to its absence in the environment at detectable levels for the dissolved fraction. Dissolved mercury was detected in almost every field blank at concentrations similar to water column samples.

Table 3-9 summarizes beach water dissolved metals data, providing frequency of detection and minimum, maximum, and median concentrations. Table 3-10 summarizes dissolved metals data for the sites sampled annually in both 1999 and 2000. Complete beach water dissolved metals data may be found in Appendix A.

Table 3-9. Dissolved Metals Detected in Beach Water Samples--MOSS Area
Frequency of Detection and Minimum, Maximum, and Median Concentrations (µg/L)

Metal	FOD % (n=62)	Minimum	Maximum	Median
Antimony	100	0.042	0.112	0.075
Arsenic	100	0.70	1.28	1.04
Cadmium	100	0.0359	0.0732	0.0622
Chromium	100	0.091	0.160	0.120
Cobalt	98	0.0140	0.0768	0.0218
Copper	100	0.291	2.730	0.375
Lead	33	0.0054	0.0422	0.0093
Mercury	98	0.00015	0.00074	0.00022
Nickel	95	0.330	0.774	0.400
Thallium	100	0.007	0.011	0.010
Vanadium	100	0.91	1.85	1.34
Zinc	23	0.37	5.34	0.66

Table 3-10. Dissolved Metals in Beach Water Samples at Sites Sampled Annually
Frequency of Detection and Minimum, Maximum, and Median Concentrations (µg/L)

Metal	FOD % (n=14)	Minimum	Maximum	Median
Antimony	100	0.079	0.108	0.094
Arsenic	100	0.88	1.23	1.10
Cadmium	100	0.035	0.064	0.0571
Chromium	100	0.107	0.140	0.125
Cobalt	100	0.024	0.093	0.037
Copper	100	0.342	1.23	0.458
Lead	100	0.007	0.074	0.013
Nickel	100	0.284	0.544	0.392
Thallium	100	0.007	0.10	0.010
Vanadium	100	1.40	2.66	1.49
Zinc	100	0.60	17.2	1.13

Statistical Analysis of Beach Water Metals Data

Preliminary analysis of beach metals data indicates the data are not normally distributed and variations of the distributions of individual metals are large. Sampling will continue through February 2002 in order to obtain two complete years of data in the MOSS area. An analysis of spatial and temporal metals concentrations at beach stations will be conducted when sampling has concluded and statistical results will be reported in a separate document.

Washington State Water Quality Criteria for Beach Metals

Table 3-11 summarizes beach water metals results and compares them to acute and chronic water quality criteria. For most of the metals, the criteria are compared to dissolved metals. The exceptions are: mercury, for which the chronic criterion is for the total fraction; and zinc, for which repeated quality control failures rendered dissolved data unusable.

The reported maximum concentrations for all metals detected in this sampling effort, with the exception of copper, were well below the associated acute and chronic water quality criteria. The reported maximum value of 2.73 µg/L for dissolved copper is close to the chronic criterion of 3.1 µg/L. The maximum concentration of dissolved copper was detected in a sample collected from Golden Gardens Park.

**Table 3-11. Puget Sound Beach Water Metals Concentrations
Compared to Published Water Quality Criteria**

Dissolved Metal^a	Concentration (µg/L)			Marine Water Quality Criteria^b	
	Minimum	Maximum	Mean	Acute (µg/L)	Chronic (µg/L)
Antimony	0.042	0.112	0.075	*	*
Arsenic	0.70	1.28	1.04	69.0	36.0
Cadmium	0.0359	0.0732	0.0622	42.0	9.3
Chromium	0.09	0.16	0.12	*	*
Cobalt	0.0140	0.0768	0.0218	*	*
Copper	0.291	2.730	0.375	4.8	3.1
Lead	<0.005 (MDL)	0.042	0.009	210.0	8.1
Mercury ^c	<0.00010 (MDL)	0.00508	0.00070	1.8	0.025 ^d
Nickel	0.330	0.774	0.400	74.0	8.2
Selenium	<0.15 (MDL)	<0.15 (MDL)	<0.15 (MDL)	290	71.0
Silver	<0.06 (MDL)	<0.06 (MDL)	<0.06 (MDL)	1.9	*
Thallium	0.007	0.011	0.010	*	*
Vanadium	0.91	1.85	1.34	*	*
Zinc ^e	0.51	8.09	1.10	95 ^d	86 ^d

^a Dissolved concentrations reported for all metals except mercury and zinc.

^b Water quality criteria from Chapter 173-201A WAC (Ecology, November 1997). Criteria are for dissolved metals except as noted.

^c Total mercury concentrations reported for comparison to marine chronic criterion.

^d Criterion is for total metal.

^e Total zinc concentrations reported because of repeated quality control failures in dissolved zinc analysis.

3.2.10 Organic Compounds in the Offshore Water Column

Monthly water column samples were collected from eight offshore stations between April 1999 and April 2000 for analysis of organic compounds. Samples were collected from three depths at each of the stations noted below.

- Admiralty Inlet (ADMIRALC14) – 5, 50, and 110 meters
- Possession Sound (POSSESSC14) – 5, 50, and 190 meters
- Point Wells (PTWELLS1) – 5, 50, and 120 meters
- Jefferson Head (KSBP01) – 5, 50, and 210 meters
- West Point Outfall (KSSK02) – 5, 30, and 55 meters
- Renton Outfall (LSEP01) – 5, 50, and 130 meters
- Fauntleroy/Vashon (LSNT01) – 5, 50, and 170 meters
- Colvos Passage (COLVOSPASS) – 5, 50, and 85 meters

The samples were analyzed for base/neutral/acid extractable semivolatile compounds (BNAs) on a monthly basis, with the exception of September 1999. The samples were analyzed on a less-than-routine basis for the following classes of compounds:

- chlorinated pesticides and polychlorinated biphenyls (PCBs) – analyzed nine times; in April, May, June, July, August, October, and November 1999 and January and April 2000;
- chlorinated herbicides – analyzed twice; in December 1999 and March 2000; and
- organophosphorus pesticides – analyzed once; in February 2000.

A total of 108 organics compounds were analyzed during this time for the MOSS study; 65 base neutral acids (BNAs), 26 chlorinated pesticides/PCBs, 10 chlorinated herbicides, and 7 organophosphorus pesticides. A complete list of the organic compounds may be found in Appendix A.

Chlorinated pesticides, PCBs, chlorinated herbicides, and organophosphorus pesticides were not detected in any offshore water column sample collected during this study.

A total of 20 different BNAs were detected one or more times in offshore water column samples during this study. Table 3-12 summarizes the compounds detected, along with the frequency of detection (FOD) for each. Complete water column organics data may be found in Appendix A.

Table 3-12. Organic Compounds Detected in Offshore Water Column Samples
Frequency of Detection

Compound	FOD/311* samples	FOD (%)
Benzyl Butyl Phthalate	8	2.6
Bis(2-ethylhexyl) Phthalate	66	21
Di-N-Butyl Phthalate	2	0.6
Di-N-Octyl Phthalate	11	3.5
Diethyl Phthalate	3	1
Dimethyl Phthalate	53	17
Benzo(a)anthracene	1	0.3
Benzo(a)pyrene	1	0.3
Benzo(b)fluoranthene	1	0.3
Benzo(k)fluoranthene	1	0.3
Chrysene	1	0.3
Fluoranthene	4	1.3
Naphthalene	3	1
Phenanthrene	16	5.1
Pyrene	7	2.3
Benzoic Acid*	29	14
Benzyl Alcohol*	6	2.9
Phenol	3	1
Caffeine	171	55
Coprostanol*	3	1.4

* Compounds were only analyzed successfully in 207 out of 311 samples.

It should be noted that several of these 20 BNA compounds were detected at a higher frequency than reported in Table 3-12. Data validation determined that many positive BNA analytical results were impacted by quality control failures that indicated probable laboratory contamination. This was especially true for the phthalate compounds. Phthalates are plasticizers that are ubiquitous, not only in the general environment, but in the analytical laboratory as well. Although care was taken during both sampling and analysis to minimize sample contamination, phthalates were regularly detected in analytical method blanks.

A method blank is a negative control sample that indicates probable laboratory contamination when an analytical result for any compound is greater than the method detection limit. When any organic compound was detected in a method blank, associated sample data for that compound were flagged "B" if the reported sample concentrations were less than five times the concentration detected in the method blank. For purposes of this report, those data points flagged "B" were considered undetected.

Table 3-13 summarizes the minimum, maximum, and median concentrations for the 20 BNA compounds detected in offshore water column samples during this study.

Table 3-13. Organic Compounds Detected in Offshore Water Column Samples
Minimum, Maximum, and Median Concentrations (µg/L)

Compound	Minimum	Maximum	Median
Benzyl Butyl Phthalate	0.0081	0.28	0.048
Bis(2-ethylhexyl) Phthalate	0.14	37	1.7
Di-N-Butyl Phthalate	0.070	0.26	0.17
Di-N-Octyl Phthalate	0.0054	0.063	0.011
Diethyl Phthalate	0.0020	0.070	0.024
Dimethyl Phthalate	0.0047	0.14	0.0068
Benzo(a)anthracene	0.014	0.014	0.014
Benzo(a)pyrene	0.017	0.017	0.017
Benzo(b)fluoranthene	0.011	0.011	0.011
Benzo(k)fluoranthene	0.0090	0.0090	0.0090
Chrysene	0.015	0.015	0.015
Fluoranthene	0.0048	0.030	0.0052
Naphthalene	0.012	0.021	0.019
Phenanthrene	0.0049	0.0086	0.0055
Pyrene	0.0048	0.037	0.0053
Benzoic Acid	0.14	1.4	0.27
Benzyl Alcohol	0.23	0.49	0.35
Phenol	0.047	0.27	0.068
Caffeine	0.0048	0.071	0.0085
Coprostanol	0.10	0.64	0.62

Phthalates

Phthalate compounds are plasticizers that are ubiquitous in the environment. As noted previously, five of the six phthalate compounds were routinely detected in laboratory method blanks. Only those samples for which the phthalate concentration was five times greater than the concentration detected in the method blank have been considered to have *reportable* phthalates. It is difficult to discern accurate phthalate concentrations in many of these samples because laboratory contamination may have had a major impact on reportable phthalate concentrations. Four of the six phthalates were detected infrequently (in less than 4% of the samples). Dimethyl phthalate and bis(2-ethylhexyl) phthalate were detected more frequently; in 17 and 21% of the samples, respectively. Phthalates did not appear to be detected more frequently or at higher concentrations at any given sampling station or depth.

Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) are found in petroleum and coal tar-related manufacturing products and can enter the marine environment directly or indirectly as combustion byproducts, introduced through atmospheric deposition and storm water runoff. PAHs are also the major constituents of creosote, which has traditionally been used as a wood preservative on docks and pilings. Reportable concentrations of nine PAHs were detected one or

more times in water column samples collected during this study. Five of these PAHs were detected only once, all in a single sample collected in November 1999 from the 5-meter sampling depth at the West Point outfall station (three of the other four PAHs were also detected in the same sample). The remaining four PAHs were detected infrequently, all found in less than 6 % of the samples.

Acid/Alcohol Compounds

Benzoic acid and benzyl alcohol were problematic compounds, analytically, and were analyzed in only 207 of the 311 samples collected during this study. Benzoic acid is a common food preservative and is also present in cigarette smoke. This compound is also naturally present in many plants, especially berries, and is a metabolic byproduct in some organisms (it is routinely detected during analysis of shellfish tissue). Benzoic acid was detected in 14 % of the water column samples with no evident spatial or temporal patterns. Benzyl alcohol and phenol were detected infrequently; in 2.9 and 1 % of the samples, respectively. Both of these compounds are present in household products, most notably cold and cough medicines. Phenol is also present in many cleaning products as a disinfectant.

Tracer Compounds

Caffeine and coprostanol are anthropogenic tracer compounds that are analyzed in receiving water as possible indicators of wastewater effluent. Reportable concentrations of coprostanol were detected in only 3 out of 311 water column samples. One of these samples was collected from the West Point outfall sampling station and two of the samples were collected from the Fauntleroy/Vashon sampling station. Reportable concentrations of caffeine were detected approximately in 55 % of the samples collected during this study. Statistical analysis does not indicate any station or depth with significantly higher concentrations of caffeine.

For all organic compounds analyzed in offshore waters, spatial and temporal comparisons between stations are not possible due to the infrequency of detection of organic compounds.

Washington State Water Quality Criteria for Organic Compounds

Washington State has not promulgated water quality criteria for any of the 20 organic compounds detected in this study. The 12 organic compounds for which there are Washington State water quality criteria for are summarized in Table 3-14 and include 9 chlorinated pesticides, total PCBs, one organophosphorus pesticide, and the BNA compound, pentachlorophenol. These 12 organic compounds were not detected in any water column samples collected during this study. For purposes of comparison, the analytical method detection limits (MDLs) for these compounds have been presented along with the Washington State acute and chronic water quality criteria in Table 3-14.

Table 3-14. Washington State Water Quality Criteria (Chapter 173-201A WAC)
vs. Analytical Method Detection Limits (all values in µg/L)

Compound	Acute	Chronic	MDL
Aldrin	0.71	0.0019	0.0047
Chlordane	0.09	0.004	0.024
Chlorpyrifos	0.011	0.0056	0.032
DDT (and metabolites)	0.13	0.001	0.0047
Dieldrin	0.71	0.0019	0.0047
Endosulfan	0.034	0.0087	0.0047
Endrin	0.037	0.0023	0.0047
Heptachlor	0.053	0.0036	0.0047
Lindane	0.16		0.0047
Pentachlorophenol	13.0	7.9	0.059
Polychlorinated Biphenyls (PCBs)	10.0	0.030	0.047
Toxaphene	0.21	0.0002	0.047

Analytical MDLs achieved during this study were lower than the acute water quality criteria for all organic compounds listed in Table 3-14. The MDLs exceeded the chronic water quality criteria, however, for all compounds except Endosulfan and pentachlorophenol.

3.2.11 Organic Compounds in Beach Water

Beach (intertidal) water samples were collected monthly from three stations and quarterly from eight stations between March and December 2000 for analysis of organic compounds. Samples were collected from a single depth at each of the stations noted below.

- Monthly Sampling – Meadowdale Beach Park, Edwards Point, Carkeek Park
- Quarterly Sampling – Picnic Point Park, Ocean Avenue, Brackett's Landing (Underwater Park), Richmond Beach (Point Wells), Boeing Creek, North Beach (Blue Ridge Park), Golden Gardens Park, Shilshole Bay

All samples were analyzed for BNAs and chlorinated herbicides on a monthly basis. The samples were also analyzed on a less-than-routine basis for the following classes of compounds:

- chlorinated pesticides and PCBs – analyzed six times; in March, April, June, July, September, and December 2000; and
- organophosphorus pesticides – analyzed eight times; in March, May, June, August, September, October, November, and December 2000.

A total of 108 organics compounds were analyzed during this study; 65 BNAs, 26 chlorinated pesticides/PCBs, 10 chlorinated herbicides, and 7 organophosphorus pesticides. A complete list of the organic compounds may be found in Appendix A.

Chlorinated pesticides, PCBs, chlorinated herbicides, and organophosphorus pesticides were not detected in any beach water sample collected during this study.

A total of 21 different BNAs were detected one or more times in beach water samples during this study. Table 3-15 summarizes the compounds detected, along with the frequency of detection (FOD) for each. Complete beach water BNA data may be found in Appendix A.

Table 3-15. Organic Compounds Detected in Beach Water Samples
Frequency of Detection

Compound	FOD/66 samples	FOD (%)
Bis(2-ethylhexyl) Phthalate	10	15
Di-N-Butyl Phthalate	2	3
Di-N-Octyl Phthalate	9	14
Diethyl Phthalate	8	12
Dimethyl Phthalate	7	11
Acenaphthene	3	4.5
Anthracene	2	3
Benzo(a)anthracene	1	1.5
Benzo(a)pyrene	2	3
Benzo(b)fluoranthene	2	3
Benzo(k)fluoranthene	2	3
Chrysene	1	1.5
Fluoranthene	21	32
Fluorene	7	11
Naphthalene	12	18
Phenanthrene	24	36
Pyrene	10	15
Caffeine	45	68
Carbazole	1	1.5
Dibenzofuran	2	3
Phenol	29	44

As with offshore water column organics data, it should again be noted that several of these 21 BNA compounds were detected at a higher frequency than reported in Table 3-15. Data validation again determined that many positive BNA analytical results were impacted by quality control failures that indicated probable laboratory contamination. As with the offshore water column data, for purposes of this report, those beach water data points flagged “B” were considered undetected.

Table 3-16 summarizes the minimum, maximum, and median concentrations for the 21 BNA compounds detected in beach water samples during this study.

Table 3-16. Organic Compounds Detected in Beach Water Samples
Minimum, Maximum, and Median Concentrations (µg/L)

Compound	Minimum	Maximum	Median
Bis(2-ethylhexyl) Phthalate	0.71	15.4	2
Di-N-Butyl Phthalate	0.53	0.95	0.74
Di-N-Octyl Phthalate	0.0064	0.83	0.0092
Diethyl Phthalate	0.082	0.25	0.1
Dimethyl Phthalate	0.0054	0.019	0.009
Acenaphthene	0.0058	0.084	0.0075
Anthracene	0.019	0.026	0.023
Benzo(a)anthracene	0.015	0.015	0.015
Benzo(a)pyrene	0.0094	0.018	0.014
Benzo(b)fluoranthene	0.0089	0.019	0.014
Benzo(k)fluoranthene	0.0078	0.02	0.014
Chrysene	0.025	0.025	0.025
Fluoranthene	0.0051	0.051	0.0088
Fluorene	0.006	0.0095	0.0067
Naphthalene	0.013	0.036	0.017
Phenanthrene	0.0052	0.048	0.0088
Pyrene	0.0052	0.032	0.011
Caffeine	0.0058	0.0463	0.01
Carbazole	0.072	0.072	0.072
Dibenzofuran	0.0051	0.0075	0.0063
Phenol	0.052	1.04	0.066

Phthalates

As with offshore water column samples, only those beach water samples for which the phthalate concentration was five times greater than the concentration detected in the method blank have been considered to have reportable phthalates. As a result of method blank contamination, there were no reportable concentrations of benzyl butyl phthalate. It is difficult to discern accurate concentrations for the other five phthalates in many of these samples, again, because laboratory contamination may have had a major impact on the reportable phthalate concentration. Four of the phthalates were detected at roughly the same frequency; between 11 and 15 %. The fifth phthalate was detected infrequently; found in 3 % of the samples. Phthalates do not appear to be detected more frequently or at higher concentrations at any given beach sampling station.

Polynuclear Aromatic Hydrocarbons

Reportable concentrations of 12 PAHs were detected one or more times in beach water samples collected during this study. PAHs were detected at all stations with the exception of Boeing Creek. Phenanthrene and fluoranthene were the most frequently detected PAHs; found in 36 and 32 % of the samples, respectively. Fluorene, naphthalene, and pyrene were detected less frequently; found in 11 to 18 % of the samples. The remaining seven reported PAHs were all detected in less than 5 % of the samples. While the range of PAH concentrations detected in

these samples was narrow, there were some spatial variations between sites both in the number of different PAHs detected and the number of times PAHs were detected at each site. Table 3-17 summarizes the distribution of PAHs detected at beach water sampling stations.

**Table 3-17. Number of PAHs Detected and Number of PAH Detections
Beach Water Sampling Stations**

Station	# PAH Compounds Detected	# of Times PAHs Were Detected
Picnic Point Park	2	3
Meadowdale Beach Park	2	4
Ocean Avenue	3	6
Brackett's Landing (UW Park)	4	11
Edwards Point	7	15
Point Wells	4	6
Boeing Creek	0	0
Carkeek Park	3	7
Blue Ridge Beach Park	3	4
Golden Gardens Park	10	17
Shilshole Bay	7	14

The four sampling stations with the highest number of PAH detections; the underwater park at Brackett's Landing, Edwards Point, Golden Gardens Park, and Shilshole Bay, are located near potential sources of creosote such as the Edmonds Ferry Dock, the Unocal Oil Pier, and Shilshole Bay Marina.

Miscellaneous Organic Compounds

Caffeine and phenol were detected, respectively, in 68 and 44 % of the intertidal water samples. Neither of these compounds exhibited any discernable spatial or temporal patterns. Carbazole was detected in one sample, collected from the sampling station at Edwards Point, near the Unocal Oil Pier. Carbazole is a constituent of crude oil and is also present in refined petroleum fuels. Dibenzofuran was detected twice, in one sample collected from the underwater park at Brackett's Landing and another collected from Shilshole Bay. Dibenzofuran is one constituent of creosote.

3.3 Sediment Chemistry Data Results

Marine sediments were collected from offshore, nearshore and beach stations as part of the ambient and point source monitoring programs (see Figures 2-1 and 2-2). Point source stations are located near treatment plant outfall pipes and combined sewer overflow (CSO) outfall pipes. Outfall stations are positioned at varying distances from the pipe to assess potential impacts from the outfall.

Sediment samples were analyzed for conventional parameters including total solids, total volatile solids, total sulfide, ammonia nitrogen, oil and grease, total organic carbon (TOC) and grain size distribution. Sediments were also analyzed for metals and organic compounds including pesticides, polychlorinated biphenols (PCBs), polyaromatic hydrocarbons (PAHs) and semi volatile organics.

Metals and ionizable organics data are presented on a dry weight basis. Non-ionizable organics data are presented on a dry weight basis when sediment TOC is less than 0.5% dry weight. Non-ionizable organics are presented normalized to organic carbon when sediment TOC is greater than 0.5% dry weight. All sediment data are provided in Appendix B.

Some stations were sampled in both 1999 and 2000, however, other stations were sampled in alternating years. Sediment samples were collected from 13 point source offshore stations near the South TP outfall in 1999. Six nearshore point source Alki stations and nine beach stations (four point source, five background) were also sampled in 1999. The Vashon Island TP outfall was sampled for the first time in 1999 to obtain baseline sediment quality information at the time the treatment plant changed jurisdiction and became the responsibility of King County. Samples were collected from 18 nearshore, point source stations during this event.

Sediment samples were collected from 18 offshore point source stations near the West Point TP and Carkeek outfalls in 2000. Five offshore ambient stations, three nearshore stations (one point source, two ambient) and six beach stations (three point source, three ambient) were also sampled in 2000.

3.3.1 Sediment Conventionals

The physical structure of the sediments and location of the sampling stations influenced the results of the conventional analyses. Grain size composition at the South TP and Elliott Bay stations was dominated by fine particles, and consequently, TOC was significantly higher. This, in turn, affected other parameters including ammonia and sulfides. Stations in Elliott Bay are also influenced by the industrial activity in the harbor.

TOC was measured in all sediment samples. Values for offshore samples collected in 1999 ranged from 1,000 to 22,379 mg/kg dry weight. The highest values were detected at South TP outfall stations, the lowest at Vashon Island TP outfall stations. Values for nearshore sediments ranged from 2,382 to 3,030 mg/kg dry weight, beach sediments ranged from 433 to 1,750 mg/kg dry weight. The nearshore and beach sediments sampled in 1999 were composed mainly of sand

and gravel. Sandy sediments typically have lower TOC values than sediments containing a high proportion of silt and clay.

TOC values for offshore samples collected in 2000 ranged from 671 to 19,011 mg/kg dry weight. The highest values were detected at stations in Elliott Bay and the Central Basin; the lowest values were detected at the West Point TP outfall stations. Values for nearshore sediments ranged from 2,469 to 24,182 mg/kg dry weight with the highest value being detected at inner Elliott Bay station LTDF01 and the lowest was at the station near the mouth of the Lake Washington Ship Canal, KSPS01. Values for beach sediments ranged from 579 to 2,070 mg/kg dry weight. The sediments at all but two beach stations, LSKR01 and KSYV02, contained less than a 1000 mg/kg TOC. TOC concentrations at these two beaches were 1,119 and 2,070 mg/kg dry weight, respectively.

Figure 3-26 shows the relationship between TOC grain size distribution. Higher concentrations of organic carbon occur with fine-grained sediments in depositional areas, whereas lower concentrations of organic carbon occur where coarse-grained sediments are found.

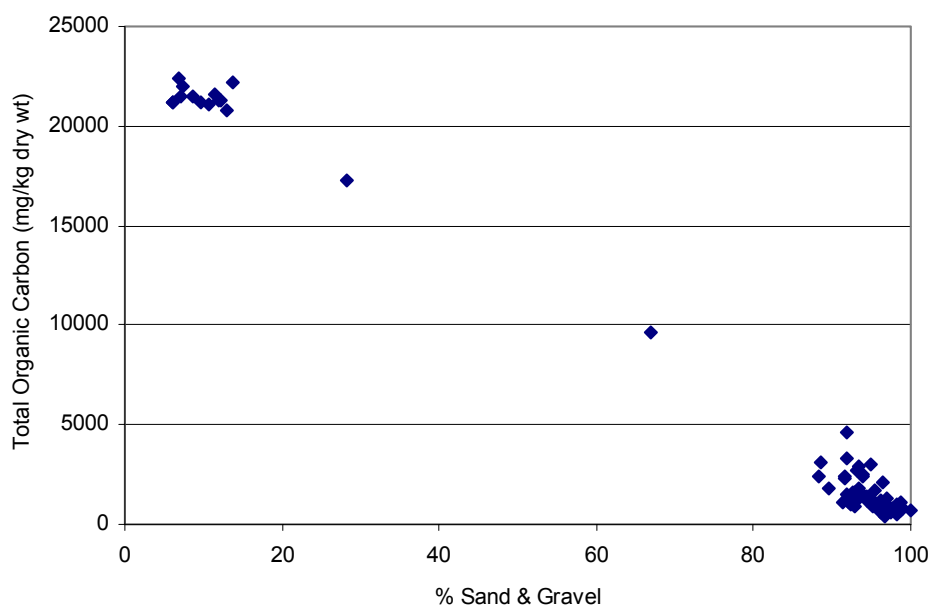


Figure 3-26. Organic Carbon vs. Grain Size for All Stations in 1999 and 2000

Sulfides were analyzed as they may be directly toxic to benthic organisms or indirectly through their ability to increase the bioavailability of metals. Sulfides were detected in 11 samples collected in 1999 from South TP outfall stations at concentrations ranging from 32 to 72 mg/kg dry weight. South TP outfall stations have significantly higher TOC than other stations, which may explain why sulfides were detected at this site and not others. Sulfides were not detected in any samples collected in 2000.

Total oil and grease analysis includes compounds such as animal fats, vegetable oils, soaps, and greases. This analysis was conducted on sediments collected from offshore, nearshore and beach stations. In 1999, total oil and grease values ranged from less than the detection limit (100 mg/kg) to 160 mg/kg. In 2000, total oil and grease values ranged from less than the detection limit to 590 mg/kg. Higher concentrations of oil and grease were detected at beach and Elliott Bay stations.

Ammonia nitrogen was analyzed in samples collected from offshore and nearshore stations. In 1999, concentrations ranged from 0.32 to 26.4 mg/kg, with the highest value occurring at the South TP station RT625ND. There did not appear to be a gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipe. Ammonia concentrations correlated most strongly with TOC. These results are consistent with results from past years that also found ammonia to be correlated to TOC.

Ammonia concentrations in 2000 ranged from 0.26 to 5.15 mg/kg with the highest value occurring at station LSML01, an offshore station in the Central Basin with relatively high TOC levels (Figure 3-27). Ammonia concentrations were also significantly higher at the Elliott Bay stations compared to the West Point and Carkeek outfall stations. There did not appear to be a concentration gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipe. High TOC levels also characterize the Elliott Bay stations.

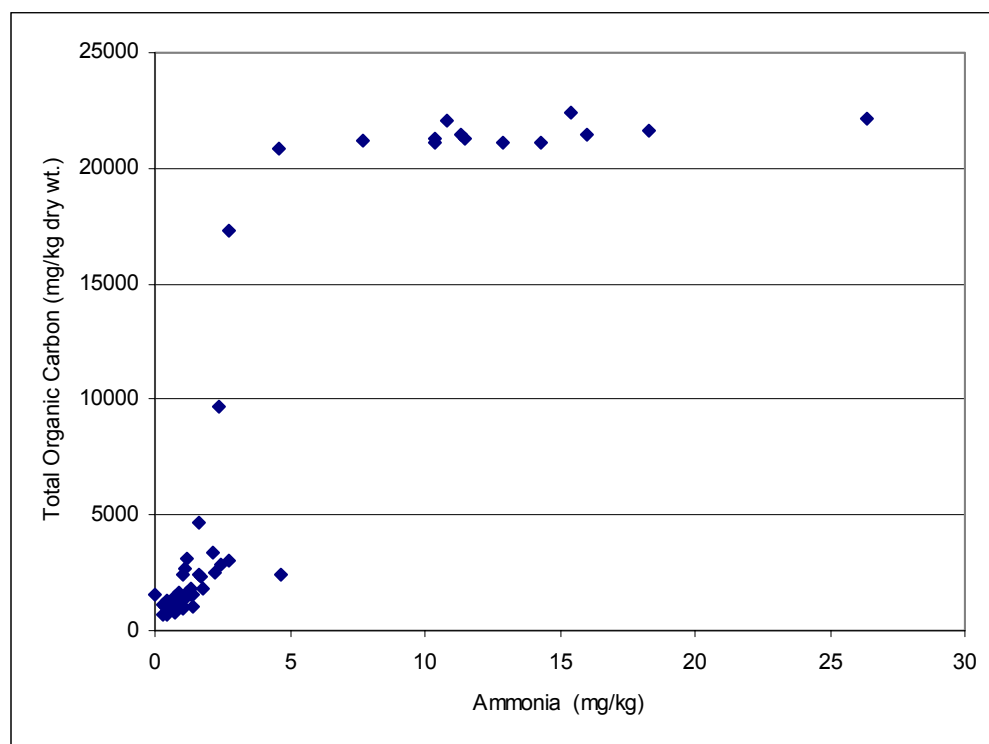


Figure 3-27. Ammonia vs. TOC

3.3.2 Sediment Metals

Sixteen metals are routinely analyzed in sediment samples. Not every metal, however, was analyzed at each station. Table 3-18 indicates which metals were analyzed at each station and the frequency of detection. Generally, results from metals analyses in 1999 and 2000 were similar to previous years. Some metals were detected more often than others. Earth metals including iron and aluminum and metals commonly used in manufacturing such as manganese, copper and zinc were the most frequently detected. Summaries of the metals analyses results are presented in Tables 3-19 and 3-20. All values are reported on a dry weight basis.

All reported 1999 metal concentrations are below the Washington State Sediment Quality Standard (SQS). Antimony, selenium and thallium were not detected in any samples. Arsenic, silver and cadmium were rarely detected. Other metals, including the earth metals, were detected frequently. The highest concentrations of most metals were generally detected in samples collected from South TP stations. Many metals have a strong association with the fine grain sediments that characterize the South TP stations (KC, 1997). Alki and Vashon Island TP outfall station sediments are predominately sandy and metals concentrations are typically lower.

Twelve sampling stations are arranged in two transects, arrayed roughly north to south around the two South TP outfall pipes. One transect runs along the end of the diffuser pipes and one along the mid-diffuser point. Analytical results indicate that there does not appear to be a concentration gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipes.

Table 3-18. Metals Sampled

	1999					2000					
	South TP	Vashon TP	Alki CSO	Beach	Frequency detected	West Point TP	Elliott Bay	Carkeek CSO	Beach	Ambient	Frequency detected
Aluminum		*		*	35	*		*	*	*	30
Antimony	*	*	*		0	*		*		*	0
Arsenic	*	*	*	*	1	*	*	*	*	*	24
Beryllium	*	*	*	*	45	*	*	*	*	*	33
Cadmium	*	*	*	*	3	*	*	*	*	*	7
Chromium	*	*	*	*	47	*	*	*	*	*	33
Copper	*	*	*	*	48	*	*	*	*	*	33
Iron	*	*	*	*	48	*	*	*	*	*	33
Lead	*	*	*	*	48	*	*	*		*	33
Manganese	*	*	*	*	48	*	*	*	*	*	33
Mercury	*	*	*	*	18	*	*	*	*	*	16
Nickel	*	*	*	*	48	*	*	*	*	*	33
Selenium	*	*	*	*	0	*	*	*	*	*	0
Silver	*	*	*	*	1	*	*	*	*	*	4
Thallium	*	*	*		0	*	*	*		*	0
Zinc	*	*	*	*	48	*	*	*	*	*	33

Table 3-19. Metals Summary for Sediments 1999

	Range (mg/kg dry weight)			Detection Frequency			Station with Highest Value		
	Beach	Offshore	Nearshore	Beach	Offshore	Nearshore	Beach	Offshore	Nearshore
Aluminum	6082-8629	NA	5661-6761	10/10	NA	25/25	JSVW04	NA	VO15SC
Antimony	NA	ND	NA	NA	0/13	NA	NA	ND	NA
Arsenic	ND	<7.4-9.47	ND	0/10	1/13	0/25	ND	RT625SD	ND
Beryllium	<0.05-0.08	0.62-0.69	0.09-0.22	7/10	13/13	25/25	MTLD03	2 stations	3 stations
Cadmium	ND	<0.44-0.51	ND	0/10	3/13	0/25	ND	RT715NSW	ND
Chromium	12.3-20.2	42.4-49.3	<0.33-25.0	10/10	13/13	24/25	KSHZ03	RT825N	AL143P
Copper	5.95-14.8	43.3-48.58	2.7-7.76	10/10	13/13	25/25	JSVW04	RT625ND	AL172S
Iron	9118-13187	28224-32241	6702-14035	10/10	13/13	25/25	JSVW04	RT825N	AL143P
Lead	2.32-9.24	23.8-33.5	2.83-8.36	10/10	13/13	25/25	JSVW04	RT625ND	AL143P
Manganese	128-311	421-571	102-319	10/10	13/13	25/25	JSVW04	RT825S	AL343N
Mercury	<0.02-0.04	0.17-0.26	<0.02-0.030	1/10	13/13	4/25	KSHZ03	RT412S	3 stations
Nickel	13-27	36.4-40.7	10.8-24.71	10/10	13/13	25/25	KSHZ03	RT825N	AL172N
Selenium	ND	ND	ND	0/10	0/13	0/25	ND	ND	ND
Silver	ND	<0.59-0.60	ND	0/10	1/13	0/25	ND	RT625ND	ND
Thallium	NA	ND	ND	NA	0/13	0/25	NA	ND	ND
Zinc	21-33	95-102	14.4-31.8	10/10	13/13	25/25	JSVW04	RT625ND	AL172S

NA Not analyzed

ND Not detected

Table 3-20. Metals Summary for Sediments 2000

	Range (mg/kg dry weight)			Detection Frequency			Station with Highest Value		
	Beach	Offshore	Nearshore	Beach	Offshore	Nearshore	Beach	Offshore	Nearshore
Aluminum	5352-6318	5452-18413	5844-9370	7/7	21/21	2/2	JSVW04	LSCI01	LTBC41
Antimony	NA	ND	ND	NA	0/23	0/3	NA	ND	ND
Arsenic	ND	<3.4-13.6	<3.4-9.82	0/7	22/23	2/3	0	LSML01	LTDF01
Beryllium	0.065-0.082	0.094-0.389	0.07-0.182	7/7	23/23	3/3	JSVW04	LSCI01	LTDF01
Cadmium	<0.17-1.98	<0.19-0.461	<0.21-0.491	3/7	2/23	2/3	MTLD03	LTCA02	LTDF01
Chromium	10.6-16.5	12.3-41.6	16.3-33.3	7/7	23/23	3/3	JSVW04	LSCI01	LTDF01
Copper	4.18-9.80	4.63-49.0	6.71-52.4	7/7	23/23	3/3	JSVW04	WPD430N	LTDF01
Iron	8248-10466	9342-28862	9095-18055	7/7	23/23	3/3	JSVW04	LSCI01	LTDF01
Lead	2.47-7.36	<2.1-39.9	7.0-60.4	7/7	22/23	3/3	JSVW04	WP215N	LTDF01
Manganese	109-160	215-793	175-271	7/7	23/23	3/3	JSVW04	WP430S	LTDF01
Mercury	<0.02-0.028	<0.3-0.852	0.033-0.524	2/7	11/23	3/3	JSVW04	LSCW02	LTDF01
Nickel	12.3-21	16.3-35.3	17.6-28.4	7/7	23/23	3/3	KSHZ03	LSCI01	LTDF01
Selenium	ND	ND	ND	0/7	0/23	0/3	ND	ND	ND
Silver	ND	<0.24-0.528	<0.27-0.818	0/7	2/23	2/3	ND	LSCW02	LSCW02
Thallium	NA	ND	ND	NA	0/23	0/3	NA	ND	ND
Zinc	19.0-33.5	19.3-94.5	23-80.5	7/7	23/23	3/3	KSYV02	LTCA02	LTDF01

NA Not analyzed

ND Not detected

Again in 2000, antimony, selenium and thallium were not detected in any samples and cadmium and silver were infrequently detected. Other metals including iron, copper, chromium and lead were detected frequently. The highest concentrations of most metals were generally detected in samples collected from Elliott Bay stations. Samples from two Elliott Bay stations, LSCW02 and LTED04, exceeded the SQS of 0.41 mg/kg dry weight for mercury in 2000. Elliott Bay sediments contain high percentages of silt and clay with which metals are often associated. Elliott Bay has an industrial harbor and waterfront that has historically been a source of metals contamination from a variety of activities. No other samples exceeded the SQS.

Carkeek and West Point outfall station sediments are predominately sand and, therefore, typically have lower metals concentrations. Twelve sampling stations are arranged in two transects, arrayed roughly north to south around the West Point TP outfall pipe. One transect runs along the end of the diffuser pipe and one along the mid-diffuser point. There does not appear to be a concentration gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipes.

3.3.3 Sediment Organics

Semivolatile organics, chlorinated pesticides and polychlorinated biphenols (PCBs) were analyzed in offshore, nearshore and beach samples. Organotins were also analyzed in offshore and nearshore samples. Dry weight and organic carbon normalized values are presented in Appendix B.

Organics data are compared with either Washington State Sediment Quality Standards (SQS) or lowest apparent effect threshold (LAET). Comparison with SQS requires organic carbon normalized data to be compared with organic carbon based standards for non-ionizable semi-volatile compounds and PCBs. Many stations in this report have low organic carbon; therefore it is not appropriate to assess compliance with regulatory standards that are organic carbon based. For stations containing less than 0.5% organic carbon, dry weight values are more appropriate and data are compared with the regulatory standards that are based upon LAETs. For stations with organic carbon content greater than 0.5%, results are compared to the organic carbon based SQSs.

Ninety-eight organic compounds were analyzed in 1999. Eleven compounds were detected in South TP outfall samples, two were detected in Alki and Vashon TP outfall samples and six were detected in beach samples. No compounds exceeded regulatory standards in 1999. Table 3-21 shows the detection frequency of organic compounds.

Samples collected from South TP stations were composed mainly of silt and clay and had organic carbon values over 2.5%. Therefore, organic carbon normalized values are compared to SQSs where appropriate. Many organic compounds have an affinity for organic rich, fine sediments that dominate at the South TP outfall stations. Compounds detected at the South TP outfall stations were primarily polyaromatic hydrocarbons (PAHs) and PCBs. PAHs are present in petroleum products and coal tar related manufacturing products and are byproducts of combustion. PAHs are also found in creosote, a compound used on pilings as a wood

Table 3-21. Organic Compounds Detected in Sediments in 1999

Compound	Range (µg/kg dry weight)	Detection Frequency	Station with Highest Value
Offshore			
Aroclor 1248	<5.3-7.52	2/13	RT625SD
Aroclor 1254	8.36-13.6	13/13	RT625SD
Aroclor 1260	5.88-10.9	13/13	RT625ND
1,2-Dichlorobenzene	<2.1-2.42	1/13	RT700NS
Benzo(a)Anthracene	<49-68.6	10/13	RT625SD
Benzo(g,h,i)Perylene	<84-91.7	1/13	RT625ND
Bis(2-Ethylhexyl)Phthalate	<50-67.7	6/13	RT700NS
Chrysene	<49-58.6	4/13	RT825N
Fluoranthene	59.2-92	13/13	RT625SP
Pyrene	75-104	13/13	RT412NW
Tri-n-butyltin	1.78-4.67	13/13	RT625NP
Nearshore			
Bis(2-Ethylhexyl)Phthalate	<20-410	8/25	VO115NW
Benzo(g,h,i)Perylene	<34-135	4/25	VO15SE
Beach			
Benzo(a)Anthracene	<16-32	1/7	KSSNO5
Benzoic Acid	<113-160	1/7	KSHZ03
Bis(2-Ethylhexyl)Phthalate	<16-32	3/7	KSSNO5
Chrysene	<16-40	1/7	KSSNO5
Fluoranthene	<16-68	1/7	KSSNO5
Pyrene	<16-46	1/7	KSSNO5

preservative. Several PAHs including pyrene, fluoroanthene and benzo(a)anthracene, were detected at most or all South TP stations. Hexachlorobenzene was not detected in 1999 but exceeded the SQS at three South TP stations in 1997. PCBs were used widely as insulating material until they were banned. Three PCBs were detected at South TP stations two of which, Aroclor 1254 and Aroclor 1260, were detected at all stations.

Bis(2-ethylhexyl)phthalate was detected at almost half the stations sampled and was one of the few compounds detected in offshore, nearshore and beach sediments. Phthalates are used in a large variety of plastics manufacturing and these compounds are becoming more ubiquitous. Bis(2-ethylhexyl)phthalate is also a common laboratory contaminant. The effect of these compounds on the aquatic environment is not completely known.

Tributyltin (TBT), used extensively as anti-fouling agents in boat paints, was detected in all South TP samples but in few samples from other sites. There did not appear to be a concentration gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipe.

Two compounds were detected at nearshore stations: benzo(g,h,i)perylene and bis(2-ethylhexyl) phthalate. Benzo(g,h,i)perylene was detected only in Vashon TP outfall sediments while bis(2-ethylhexyl) phthalate was detected in both Alki and Vashon TP sediments. The highest phthalate concentrations were detected in Vashon TP outfall sediments. Again, there was no apparent concentration gradient or pattern among the outfall stations with respect to distance from the outfall pipe.

Six compounds were detected in beach sediments; five of these were detected exclusively at a single station, KSSN05. These five compounds included bis(2-ethylhexyl)phthalate and four PAHs. KSSN05 is the nearest beach station to the West Point TP outfall and has the highest TOC levels of the beach stations. Benzoic acid was detected at a single beach station, KSHZ03, near the Carkeek CSO. Benzoic acid is used as a food preservative and an anti-fungal agent; however, it is also a degradation product produced by metabolic processes and is frequently found in shellfish.

Ninety-eight organic compounds were analyzed in 2000. Twenty-four compounds were detected in offshore samples, 24 were detected in nearshore samples and one was detected in beach samples. Tables 3-22 and 3-23 show the frequency of organic compounds detected. Most of the detected compounds were PAHs. No organic compounds exceeded regulatory standards in 2000.

The majority of compounds detected in offshore sediments were PAHs. The highest concentrations of most compounds were detected at West Point stations, particularly WP215N. Two compounds exceeded SQS at station WP230P in 1998, but not in 2000. Two phthalates, benzyl butyl phthalate and bis(2-ethylhexyl)phthalate were also detected in nearly all Carkeek and West Point TP stations. TBT was not detected in West Point or Carkeek sediments, only in Elliott Bay samples. There did not appear to be a concentration gradient or any consistent differences among the outfall stations with respect to distance from the outfall pipes. Elevated levels of compounds did however, seem to correlate with high TOC values. The stations with the highest concentrations of organics, WP215N and WPD430S, also had the highest organic carbon levels.

Samples collected from the Elliott Bay nearshore stations were composed mainly of silt and clay and had organic carbon values over 2.5%, therefore, organic carbon normalized values are compared to SQS criteria. The majority of compounds detected in nearshore sediments were PAHs. The nearshore stations are located along the waterfront in Elliott Bay. Several compounds were detected at all stations; including benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene and pyrene. A combination of industrial activities and fine sediments in Elliott Bay are responsible for the typically elevated PAHs that have historically been detected at these stations. As in past years, LTDF01 generally had the highest values. Despite having elevated concentrations of organic compounds, no station exceeded the SQS.

Only a single compound was detected in one beach sample in 2000. Benzoic acid was detected at station KSYV02, near Elliott Bay.

Table 3-22. Organic Compounds Detected in Offshore Sediments in 2000

Compound	Range (µg/kg dry weight)	Detection Frequency	Station with Highest Value
Offshore			
Acenaphthylene	<19-39	1/23	WP215N
Anthracene	<19-80	3/23	WP215N
Benzo(A)Anthracene	<20-291	9/23	WP215N
Benzo(A)Pyrene	<20-462	9/23	WP215N
Benzo(B)Fluoranthene	<20-370	6/23	WP215N
Benzo(G,H,I)Perylene	<20-297	8/23	WP215N
Benzo(K)Fluoranthene	<20-141	4/23	WP215N
Benzoic Acid	61-171	18/23	WP1500SR
Benzyl Butyl Phthalate	23-28	18/23	WP215N
Bis(2-Ethylhexyl)Phthalate	<19-677	16/23	CK200S
Chrysene	<20-289	10/23	WP215N
Di-N-Butyl Phthalate	<19-36	1/23	WPD215S
Dibenzo(A,H)Anthracene	<19-48	1/23	WP215N
Fluoranthene	<20-491	14/23	WP215N
Fluorene	<19-24	1/23	WP215N
Indeno(1,2,3-Cd)Pyrene	<20-290	8/23	WP215N
Phenanthrene	<20-287	9/23	WP215N
Phenol	<33-38	1/23	WP1500SR
Pyrene	<20-324	12/23	WP215N
Aroclor 1248	<17-42.5	1/23	WP430N
Aroclor 1260	<17-162	1/23	LSCW02
Tri-n-butyltin	<0.3-25.7	2/23	LTED04

Table 3-23. Organic Compounds Detected in Nearshore and Beach Sediments in 2000

Compound	Range (µg/kg dry weight)	Detection Frequency	Station with Highest Value
Nearshore			
Acenaphthene	<15-74	1/3	LTDF01
Acenaphthylene	<22-55	1/3	LTDF01
Benzo(a)Anthracene	115-658	3/3	LTDF01
Benzo(a)Pyrene	158-915	3/3	LTDF01
Benzo(b)Fluoranthene	<116-1155	3/3	LTDF01
Benzo(g,h,i)Perylene	108-398	3/3	LTDF01
Benzo(k)Fluoranthene	65.8-478	3/3	LTDF01
Benzyl Butyl Phthalate	<22-29	1/3	LTDF01
Bis(2-Ethylhexyl)Phthalate	28.8-344	3/3	LTBC41
Carbazole	<37-148	2/3	LTDF01
Chrysene	135-1191	3/3	LTDF01
Dibenzo(a,h)Anthracene	<59-118	1/3	LTDF01
Fluoranthene	209-1102	3/3	LTDF01
Fluorene	<22-102	2/3	LTDF01
Indeno(1,2,3-Cd)Pyrene	101-422	3/3	LTDF01
Phenanthrene	132-675	3/3	LTDF01
Pyrene	294-1224	3/3	LTDF01
4,4'-DDD	<1.8-4.7	1/3	LTDF01
Aroclor 1254	<18-64.4	1/3	LTBC41
Aroclor 1260	37-95	3/3	LTDF01
Tri-n-butyltin	<0.3-535	2/3	LTBC41
Beach			
Benzoic Acid	<115-137	1/8	KSYV02

3.3.4 Benthic Community Results

Marine benthic communities are useful indicators of sediment quality as they integrate the effects of physical, chemical, and water quality conditions. Organisms in the community spend their lives in contact with sediment and water at the sediment/water interface, within the sediments, and with interstitial or pore water. The potential for chemical contaminants within these three matrices to be consumed or absorbed by benthic organisms could lead to unhealthy organisms, stressed communities, and possibly to the bioaccumulation/magnification of these contaminants to higher levels in the food web.

In 1999, benthic community monitoring was conducted at the South Plant TP outfall at six stations placed in a transect at various distances around the outfall. Samples were collected in conjunction with sediment chemistry samples. In 2000, benthic community monitoring was

conducted at the West Point TP outfall also at six stations placed in a transect at various distances around the outfall. Sediment samples for both chemistry and benthic community analyses are collected every other year at each site.

There are various methods and techniques used to analyze benthic community data. The two primary divisions for characterizing benthic communities include measuring the functional characteristics of the community (i.e., trophic indices and food web studies) and by examining the structural characteristics of the community (i.e., diversity, richness and abundance measures). Structural measures are typically evaluated for permitting purposes, therefore, King County analyzes and characterizes benthic communities at the West Point and South Plant TP outfalls using the following metrics.

- Shannon-Wiener Diversity Index
- Pielou's Evenness Measure
- Swartz's Dominance Index
- Species Abundances and Richness Measures
- Percent of Total Organisms
- Numerically Dominant Species
- Infaunal Biomass

The results for each of these metrics are summarized in the following sections. The average and standard deviation of the first four measures for each South Plant and West Point station are shown Table 3-24.

Shannon-Wiener Diversity Index

The Shannon-Wiener index is one of the most widely used diversity indices due to its ease of calculation and its relative independence of sample size. This index uses the total number of species in a sample as well as the abundance of single species to determine diversity. High diversity values are seen in areas with many different species and low environmental stress, while low values are seen in areas with few species and high environmental stress. Shannon-Wiener diversity values were calculated using the following equation:

$$H' = -\sum_{i=1}^S P_i \log_2 P_i$$

Where H' = Shannon-Wiener index
 P_i = Proportion of total sample represented by species i
 S = The number of taxa to which individuals have been allocated

Average Shannon-Wiener diversity values for the West Point samples ranged from 5.56 (Station WP215S) to 6.10 (Stations WP430S and WP230P). At the South Plant outfall, the average Shannon-Wiener diversity values ranged from 3.12 (Station RT2500R) to 3.98 (Station RT625ND).

Table 3-24. Summary of Benthic Indices and Species Abundance

South Plant	RT2500R	RT412N	RT625ND	RT700NS	RT625SD	RT412S
Average Shannon-Wiener	3.12	3.44	3.98	3.38	3.69	3.16
standard deviation	0.31	0.14	0.25	0.12	0.39	0.2
Average Evenness	0.59	0.63	0.68	0.63	0.64	0.59
standard deviation	0.06	0.05	0.05	0.04	0.05	0.03
Average Swartz's Index	4.33	5.33	7.67	5	6	4.33
standard deviation	0.58	0.58	2.08	0	1.73	0.58
Average Total Abundance	543	546	486	491	555	633
standard deviation	240	194	156	266	109	184
Average Total Species	41	45	57	42	55	41
standard deviation	7	6	2	14	6	5
Average Biomass (grams)	77.08	184.14	117.05	162.96	146.1	141.06
standard deviation	69.53	29.1	17.93	102.14	14.85	80.17
% gravel	0.3	0.3	1.2	0.3	2.2	0.3
% sand	8.4	7	12.5	9.3	9.2	12
% silt	65.4	61.5	57.6	59.2	59.1	59
% clay	26.3	31.2	29.8	32.1	29	28.9
West Point	WP1500N	WP430N	WP215N	WP230P	WP215S	WP430S
Average Shannon-Wiener	5.88	5.85	5.94	6.1	5.56	6.1
standard deviation	0.18	0.27	0.2	0.14	0.29	0.13
Average Evenness	0.88	0.83	0.81	0.83	0.9	0.91
standard deviation	0.03	0.05	0.09	0	0.06	0.03
Average Swartz's Index	39.3	40.3	44.7	43.7	30	44.3
standard deviation	3.21	6.66	2.31	4.73	5.2	5.51
Average Total Abundance	339	558	963	871	238	264
standard deviation	52	175	595	262	171	76
Average Total Species	106	138	173	162	80	106
standard deviation	6	32	54	19	33	22
Average Biomass (grams)	5.28	9.95	17.93	15.17	5.05	4.55
standard deviation	1.02	9.24	1.31	6.79	3.49	1.66
% gravel	0.1	2.3	2.4	9.4	1.8	3.6
% sand	92.2	89.4	89.4	80.2	93.4	89.9
% silt	4.3	4.5	3	6.6	2.9	4.5
% clay	3.4	3.8	5.2	3.8	1.9	2

Pielou's Evenness Measure

Pielou's Evenness Measure is a measure of diversity that is commonly used in conjunction with the Shannon-Wiener index. Evenness was calculated using the following equation:

$$J = H' / \log_2 S$$

Where J = Evenness
 H' = Shannon-Wiener index
 S = The number of taxa to which individuals have been allocated

Evenness values close to 1.0 represent a sample composed of several different species while low evenness values indicate a sample composed of only a few dominant species. Average evenness values ranged from 0.81 (Station WP215N) to 0.91 (Station WP430S) for the West Point samples. For the South Plant samples, average evenness ranged from 0.59 (Stations RT2500R and RT412S) to 0.68 (Station RT625ND).

Swartz's Dominance Index

Swartz's Dominance Index is another diversity index that measures the minimum number of species whose abundance makes up 75% of the total sample abundance. Low values indicate a sample with little diversity while high values indicate a sample composed of many species. Average Swartz's index values for the West Point samples ranged from 30.0 (Station WP215S) to 44.7 (Station WP215N). At the South Plant outfall, average Swartz's index values ranged from 4.33 (Station RT412S) to 7.67 (Station RT625ND).

Species Abundance and Richness Measures

The average total abundance (the total number of organisms) varied from 238 (Station WP215S) to 963 (Station WP215N) for the West Point samples. At the South Plant outfall, the average total abundance varied from 486 (Station RT625ND) to 633 (Station RT412S). Table 3-24 also shows the average total abundance, average total number of species, and average total biomass for the South Plant and West Point samples. Total number of species and total biomass followed the same pattern as total abundance for the West Point samples: higher values were observed at the northern stations and lower values at the southern stations.

Percent of Total Organisms

The percent of total organisms in each major taxa group is shown in Figure 3-28. All the stations in each area had similar assemblages. However, the West Point stations tended to have a greater proportion of polychaetes and a lesser proportion of molluscs than the South Plant stations.

Numerically Dominant Species

Even though polychaetes represented a larger proportion of the total abundance at the West Point stations, the most abundant species at all of the West Point stations was the mollusc *Hyatella arctica* (Table 3-25). Its average abundance ranged from 18 (Station WP430S) to 201 (Station WP215N). At the South Plant outfall, the same three species (*Axinopsida serricata*, *Euphilomedes producta*, and *Macoma carlottensis*) were among the five most abundant species at each of the stations (Table 3-26). Together, these three species represented 47.5% (Station RT625ND) to 67.3% (Station RT2500R) of the total number of individuals found at a given station.

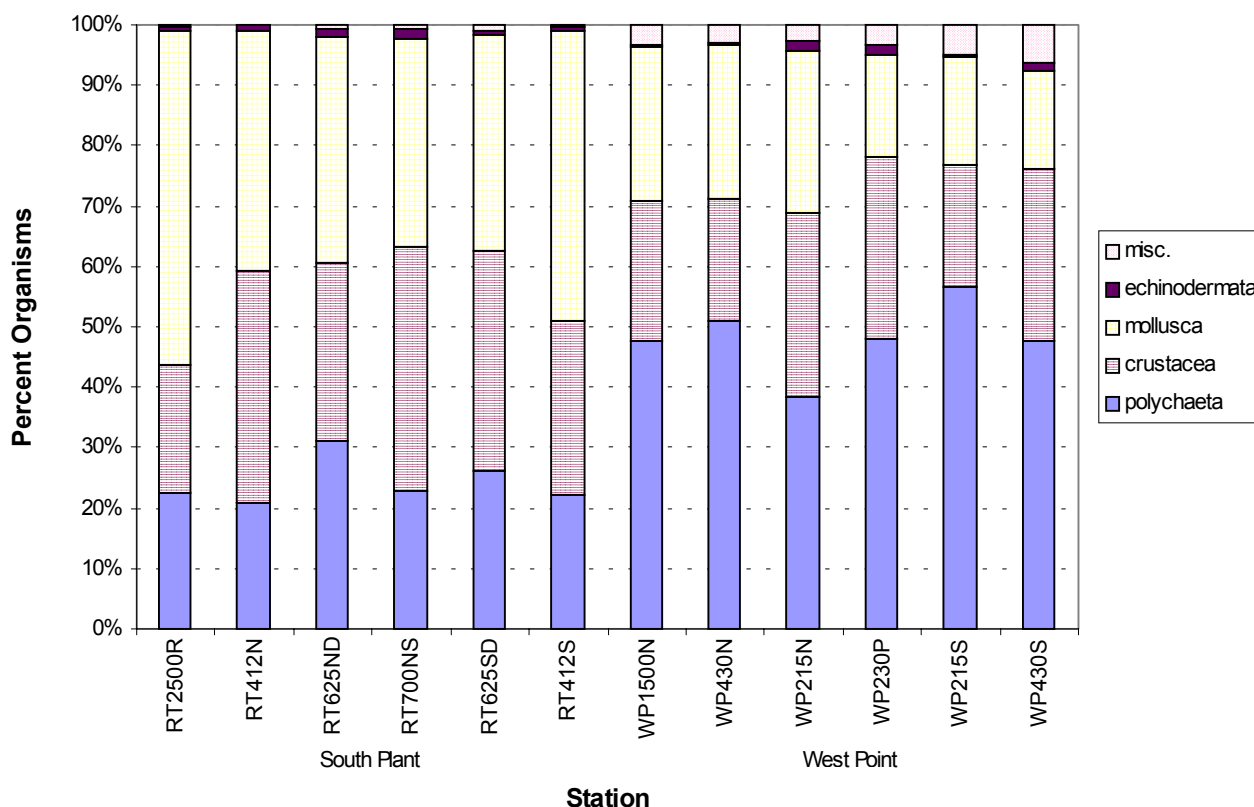


Figure 3-28. Percent Organisms in the Major Taxa Groups

Factors Effecting Species Distributions

Sediment grain size is typically a major factor in determining dominant species, total number of species, and total biomass. The sediment grain size distribution at each station is included in Table 3-24. *H. arctica*, the most abundant species at West Point (80 – 92% sand), typically burrows into soft rock and sand (Rogers, 1908). *A. serricata* and *M. carlottensis*, abundant species at the South Plant outfall (86 – 92 % fines), are commonly found in muddy areas of Puget Sound (Gustafson et al., 2000). Llansó (1998) observed that sandy areas, such as the West Point stations, tend to have higher numbers of species. However, sandy areas also tend to have lower biomass while areas with mostly fine sediments, such as the South Plant stations, have higher biomass (Lie, 1974).

Table 3-25. Dominant Species at West Point Outfall Stations

Station	Dominant Species	Taxonomic Group	Average Number of Individuals	Percent of Total Abundance
WP1500N	<i>Hiatella arctica</i>	Mollusca	42	12.5
	<i>Rhepoxynius abronius</i>	Crustacea	19	5.7
	<i>Exogone lourei</i>	Polychaeta	13	3.8
	<i>Caprella irregularis</i>	Crustacea	11	3.2
	<i>Photis spp.</i>	Crustacea	11	3.1
WP430N	<i>Hiatella arctica</i>	Mollusca	89	15.9
	<i>Pholoides asperus</i>	Polychaeta	30	5.3
	<i>Ampharete cf crassiseta</i>	Polychaeta	24	4.4
	<i>Byblis millsii</i>	Crustacea	22	4
	<i>Exogone lourei</i>	Polychaeta	21	3.7
WP215N	<i>Hiatella arctica</i>	Mollusca	201	20.8
	<i>Photis spp.</i>	Crustacea	55	5.7
	<i>Erichthonius rubicornis</i>	Crustacea	41	4.3
	<i>Byblis millsii</i>	Crustacea	28	2.9
	<i>Eudorella pacifica</i>	Crustacea	26	2.7
WP230P	<i>Hiatella arctica</i>	Mollusca	89	10.2
	<i>Pholoides asperus</i>	Polychaeta	52	6
	<i>Photis spp.</i>	Crustacea	44	5
	<i>Erichthonius rubicornis</i>	Crustacea	42	4.9
	<i>Proclea graffi</i>	Polychaeta	36	4.1
WP215S	<i>Hiatella arctica</i>	Mollusca	34	14.3
	<i>Dipolydora cf akaina</i>	Polychaeta	17	7.1
	<i>Neosabellaria cementarium</i>	Polychaeta	16	6.9
	<i>Cirratulus cf robustus</i>	Polychaeta	11	4.4
	<i>Byblis millsii</i>	Crustacea	9	3.9
WP430S	<i>Hiatella arctica</i>	Mollusca	18	6.9
	<i>Hippomedon coecus</i>	Crustacea	13	5.1
	<i>Byblis millsii</i>	Crustacea	10	3.7
	<i>Pholoides asperus</i>	Polychaeta	9	3.5
	<i>Rhepoxynius abronius</i>	Crustacea	9	3.4

Table 3-26. Dominant Species at South Plant Outfall Stations

Station	Dominant Species	Taxonomic Group	Average Number of Individuals	Percent of Total Abundance
RT2500R	<i>Axinopsida serricata</i>	Mollusca	185	34
	<i>Macoma carlottensis</i>	Mollusca	103	19
	<i>Euphilomedes producta</i>	Crustacea	78	14.3
	<i>Ampharete acutifrons</i>	Polychaeta	55	10.1
	<i>Pectinaria californiensis</i>	Polychaeta	31	5.6
RT412N	<i>Macoma carlottensis</i>	Mollusca	133	24.4
	<i>Euphilomedes producta</i>	Crustacea	118	21.7
	<i>Axinopsida serricata</i>	Mollusca	75	13.7
	<i>Eudorellopsis integra</i>	Crustacea	64	11.7
	<i>Pectinaria californiensis</i>	Polychaeta	37	6.7
RT625ND	<i>Axinopsida serricata</i>	Mollusca	83	17
	<i>Macoma carlottensis</i>	Mollusca	77	15.9
	<i>Euphilomedes producta</i>	Crustacea	71	14.6
	<i>Ampharete acutifrons</i>	Polychaeta	52	10.7
	<i>Calliopius pacificus</i>	Crustacea	38	7.8
RT700NS	<i>Euphilomedes producta</i>	Crustacea	117	23.9
	<i>Macoma carlottensis</i>	Mollusca	83	17
	<i>Axinopsida serricata</i>	Mollusca	80	16.3
	<i>Eudorellopsis integra</i>	Crustacea	60	12.2
	<i>Ampharete acutifrons</i>	Polychaeta	42	8.5
RT625SD	<i>Euphilomedes producta</i>	Crustacea	126	22.8
	<i>Macoma carlottensis</i>	Mollusca	108	19.5
	<i>Erichthonius rubicornis</i>	Crustacea	86	15.5
	<i>Axinopsida serricata</i>	Mollusca	71	12.7
	<i>Ampharete acutifrons</i>	Polychaeta	56	10.2
RT412S	<i>Macoma carlottensis</i>	Mollusca	201	31.8
	<i>Euphilomedes producta</i>	Crustacea	131	20.8
	<i>Axinopsida serricata</i>	Mollusca	84	13.3
	<i>Ampharete acutifrons</i>	Polychaeta	64	10.2
	<i>Pectinaria californiensis</i>	Polychaeta	43	6.7

3.4 Shellfish Data Results

Shellfish tissue samples were collected from beaches as a part of the ambient and point source monitoring programs. Samples consisted exclusively of the butter clam, *Saxidomus giganteus*, (whole tissues). This was a new protocol starting in 1998. Prior to that time, samples were comprised of several different species, i.e., whatever was the most prevalent at a particular beach. The change to butter clams was initiated in order to facilitate comparisons between stations and to assist in assessing temporal trends. Different feeding strategies can affect results,

and mixing species that are surface deposit feeders (e.g., *Macoma* sp.) with clams that are filter feeders (e.g., butter, littleneck, and manila clams) does not allow for direct comparisons between results. The various species also contain different amounts of lipids that may also affect results. Only general comparisons between data collected prior to 1998 and more recent results can be made, however, more meaningful comparisons between 1998 data and current data are now possible.

Shellfish tissues collected in 1999 and 2000 from four point source stations and two ambient stations were analyzed for semivolatile organics, pesticides, PCBs and metals. Stations included KSHZ03 (Carkeek), KSSN04 (West Point), KSSN05 (West Point), LSKR01 (Alki Point), JSVW04 (Richmond Beach), and MTL03 (Normandy Park). Shellfish tissue from the following three point source and six ambient stations were analyzed for fecal coliform and enterococcus bacteria; KSHZ03, KSSN04, LSKR01, JSVW04, MTL03, MTEC01 (Seahurst Park), KSLU03 (Golden Gardens), MSSM05 (Tramp Harbor) and KRJY01 (Fay Bainbridge State Park). Results are provided in Appendix C and are presented on a wet weight basis unless otherwise noted. Dry weight values for metals are also provided in Appendix C.

3.4.1 Lipids

The lipid content of shellfish tissue samples is analyzed as it effects the accumulation of metals and organic compounds. Lipids constituted 0.44 to 0.6 percent of shellfish tissue in 1999 and 0.31 to 0.49 percent of shellfish tissue in 2000 (Figure 3-29). Values in 1999 were higher than 2000 at every station.

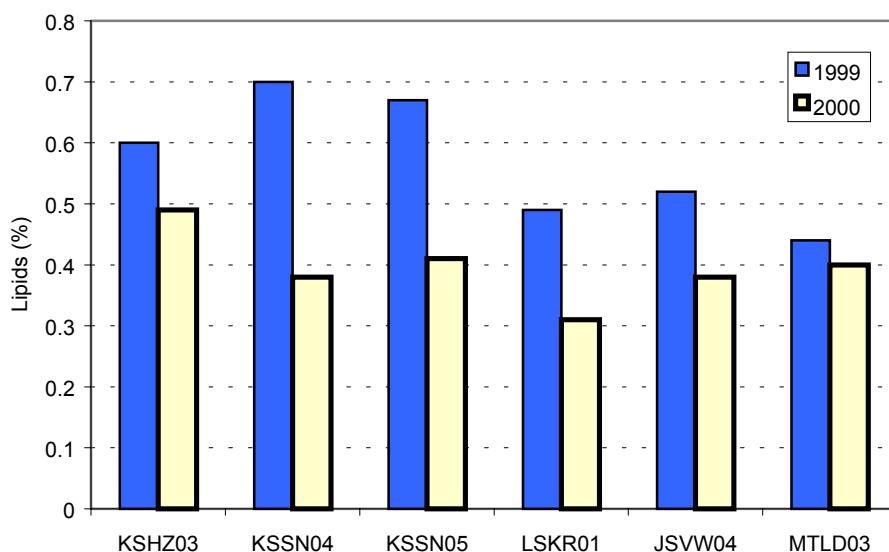


Figure 3-29. Percent Lipids in Shellfish

3.4.2 Metals

State and federal criteria do not exist for acceptable levels of metals in shellfish tissues. The U.S. Food and Drug Administration (FDA), however, has established guidance values termed Levels of Concern for mollusks for five metals: arsenic, cadmium, chromium, lead, and nickel. These guidance values are risk-based and differ for children and adults. For comparative purposes, the lower (i.e., more protective) of the two values was chosen. Table 3-27 shows the Levels of Concern for the five metals (FDA 1993a, b, c, d, e). The FDA has established an Action Level in fish and shellfish tissues of 1.0 mg/kg for mercury (FDA, 1995). Food products that exceed the Action Level cannot be commercially traded, an important distinction from Levels of Concern.

Table 3-27. FDA Levels of Concern for Shellfish Tissues

	Level of Concern (mg/kg wet wt.)
Arsenic	55
Cadmium	3
Chromium	11
Lead	0.8
Nickel	80

Eleven metals were analyzed in shellfish tissue in 1999, fourteen in 2000. No samples in 1999 or 2000 exceeded the Levels of Concern or the Action Level for mercury. Beryllium was not detected in any sample either year. Cadmium, chromium, lead, mercury, nickel, selenium, and zinc concentrations varied only slightly between stations and were similar to values detected from previous studies (NOAA, 1981). Station MTL03 generally had the highest concentrations detected for most of the metals in 1999, KSSN04 in 2000. Copper was unusually high at JSVW04 in 1999, 21.4 mg/kg dry weight, which is nearly twice as high as the highest copper value from previous years. The copper concentration in clams from this station in 2000, however was 7.0 mg/kg dry weight and similar to past results with the exception of 1999. There was not a statistical correlation between metals values and percent lipid content.

3.4.3 Organics

The same six stations that were monitored for metals were monitored for organics, which included semivolatile organics, pesticides and PCBs. Of all the compounds analyzed, only one was detected: benzoic acid. Benzoic acid was detected in all samples at concentrations ranging from 2,610 to 7,710 mg/kg. Benzoic acid is used as a food preservative and an anti-fungal agent. Benzoic acid is also a degradation product produced by metabolic processes and has always been detected in shellfish samples in the past. Benzoic acid concentrations were not correlated to percent lipid concentration.

3.4.4 Bacteria

Fecal coliform and enterococcus bacteria were analyzed in shellfish tissue collected from six ambient stations and three point source stations from May through September in 1999 and 2000. Shellfish bacteria results can be found in Appendix C.

Fecal coliform counts varied between stations and month to month. Stations near West Point (KSSN04), Seahurst Park (MTEC01) and Normandy Park (MTLD03) had the lowest bacteria counts from May to September 1999. During this five month period, counts at all monitoring stations ranged from less than 20 to 7000 MPN/100g with the highest count detected at Tramp Harbor (MSSM05) in June. (Figure 3-30). Statistical analyses found MSSM05 to have significantly higher bacteria counts than the other stations.

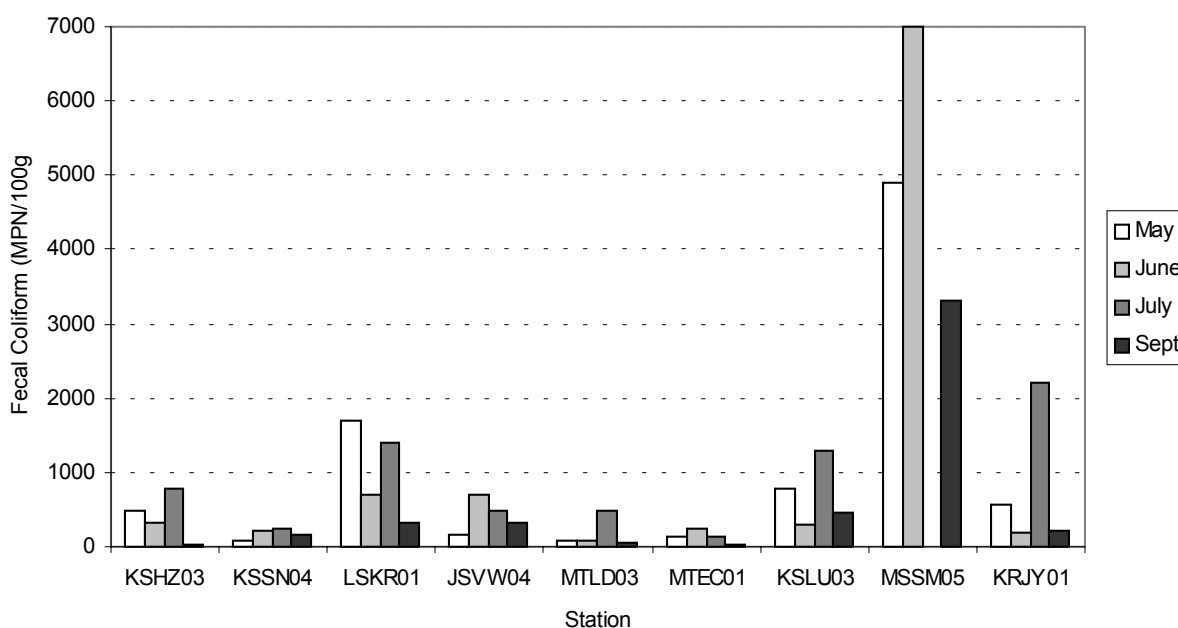


Figure 3-30. Fecal Coliform Concentrations in Shellfish in 1999

Stations near Carkeek Park (KSHZ03), Seahurst Park (MTEC01) and Normandy Park (MTLD03) had the lowest fecal coliform bacteria counts from May to September 2000 (Figure 3-31). During this five month period, counts at all monitoring stations ranged from less than 20 to 92,000 MPN/100g. The highest recorded counts in 2000 occurred at West Point in May. Extremely high concentrations also occurred at Fay Bainbridge and Tramp Harbor in August. Counts were generally lowest in September. No significant rainfall events occurred on the days preceding sample collection in 2000.

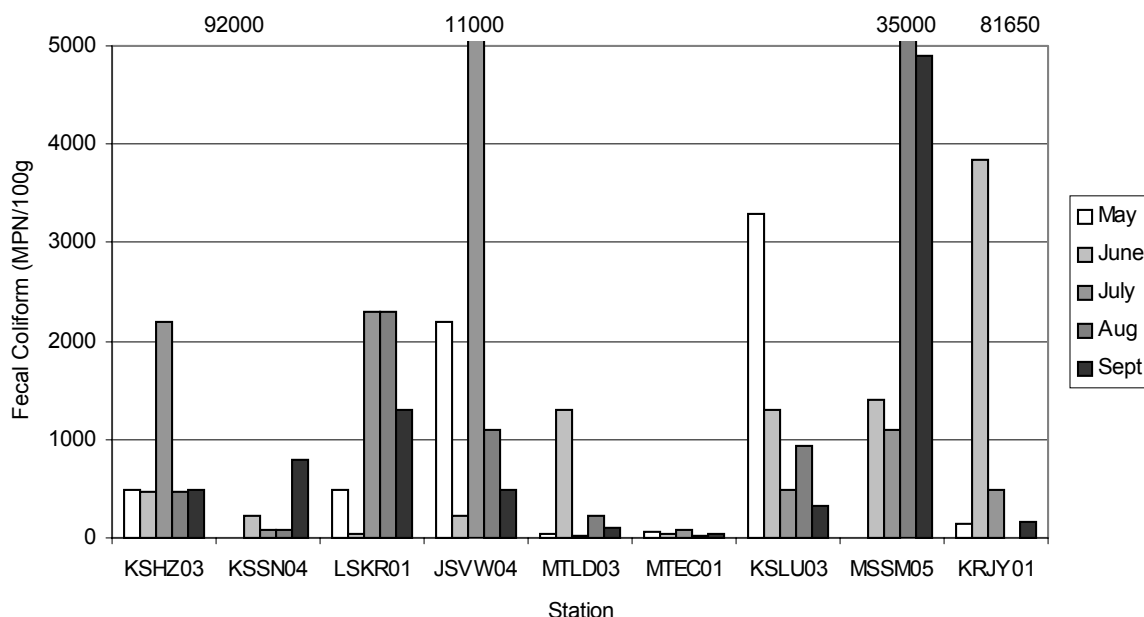


Figure 3-31. Fecal Coliform Concentrations in Shellfish in 2000

The relationship between fecal coliform counts in the water column and in shellfish was evaluated. In past years a consistent relationship has not been detected. Fecal coliform counts in water and shellfish samples that were collected on the same day from the same station in 1999 were correlated. No such correlation was observed in 2000. The lack of a constant association between fecal coliform concentrations in shellfish and overlying water is consistent with the results of other studies.

Enterococcus concentrations ranged from less than 50 to 92,000 MPN/100g in 1999 (Figure 3-32). The highest enterococcus counts were detected at Fay Bainbridge State Park (KRJY01) in July. The May sampling event was preceded by several rain events including a significant event of 0.65 inches on the day of or day before samples were collected. Carkeek (KSHZ03) and Richmond Beach (JSVW04) consistently had the lowest counts. The lowest counts at most stations were generally detected in September. No statistically significant differences were detected between stations for enterococcus. Fecal coliform and enterococcus counts were not correlated.

Enterococcus counts ranged from 20 to 22,000 MPN/100g in 2000. Seahurst Park (MTEC01), West Point (KSSN04) and Normandy Park (MTLD03) consistently had the lowest counts (Figure 3-33). The highest count was detected at Tramp Harbor in August. High counts were also detected at Fay Bainbridge in August and Alki Point (LSKR01) in May and July.

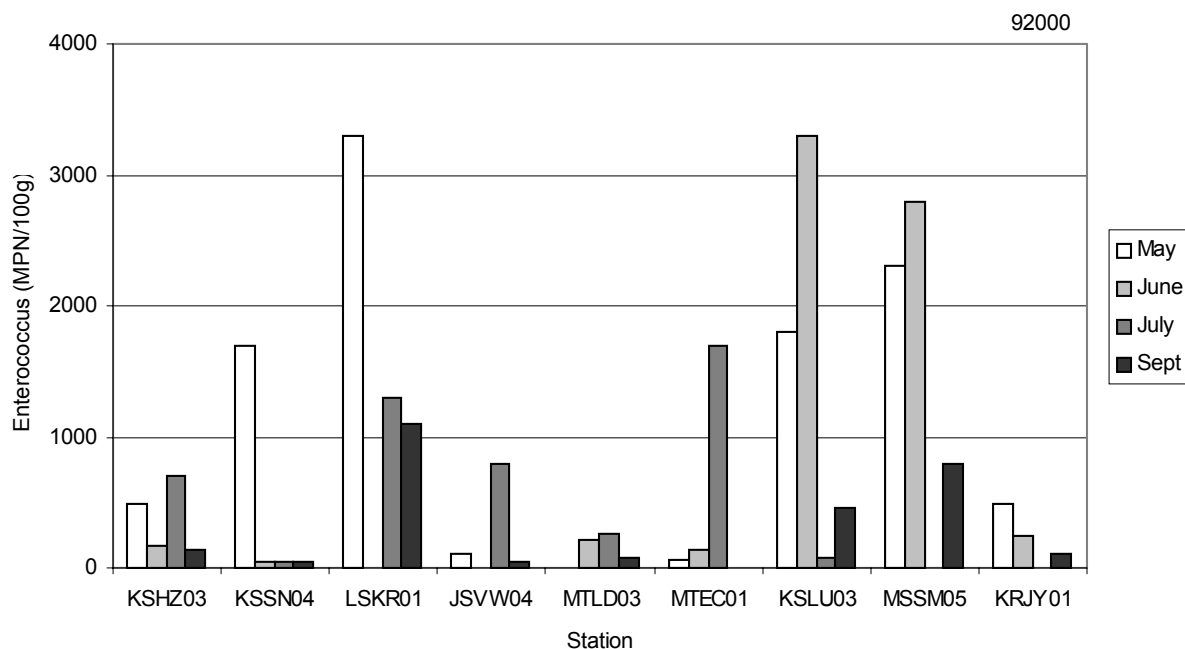


Figure 3-32. Enterococcus Counts in Shellfish in 1999

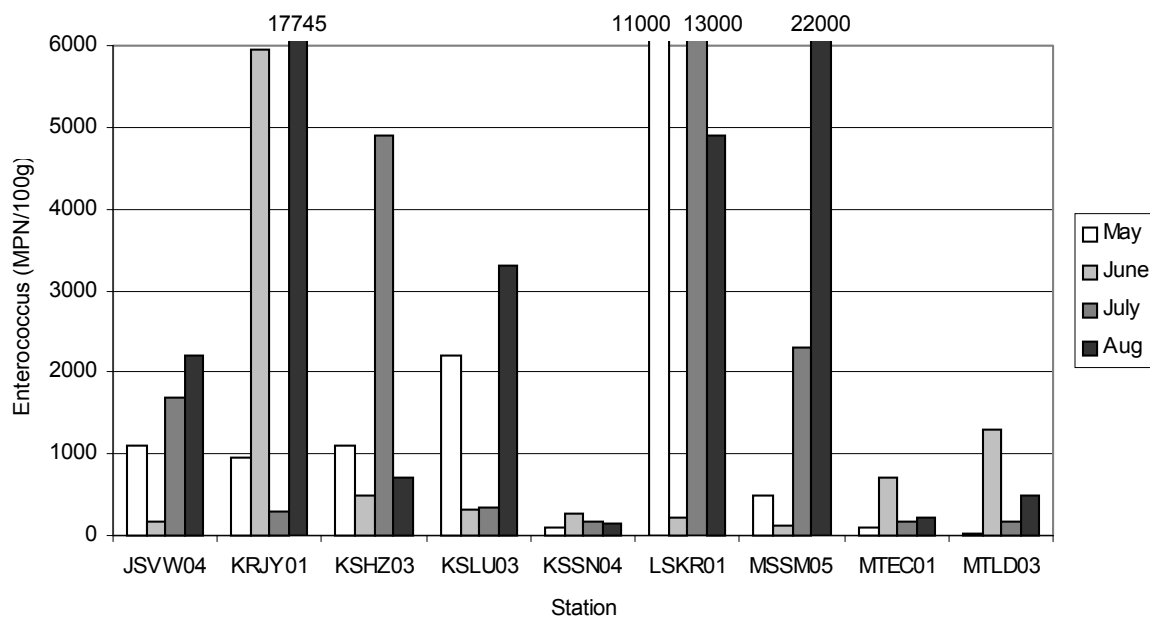


Figure 3-33. Enterococcus Concentrations in Shellfish in 2000

Although fecal coliform counts in shellfish and the water column were not correlated in 2000, enterococcus and fecal coliform counts were found to be correlated (Figure 3-34).

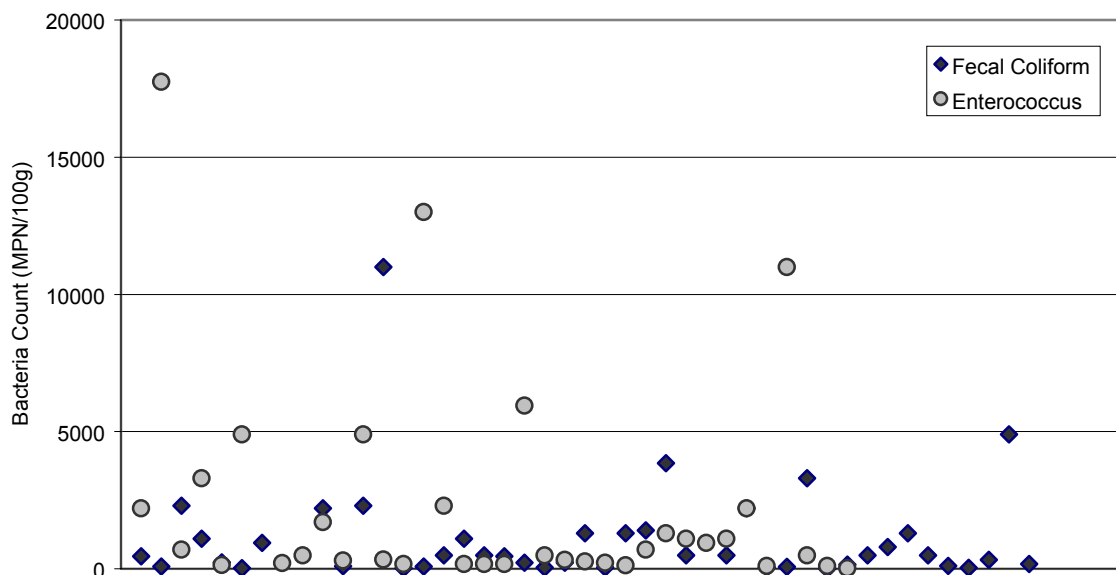


Figure 3-34. Enterococcus vs. Fecal Coliform in 2000

3.5 Macroalgae Data Results

Macroalgae samples were collected from nine beaches in 1999 and eight beaches in 2000. Samples consisted entirely of the most prevalent edible algae, *Ulva fenestrata* (known as sea lettuce) and were analyzed for metals only. All macroalgae data are presented on a dry weight basis in Appendix D.

Algae from four point source and four ambient stations were analyzed for 13 metals in 1999. Aluminum was added in 2000. The point source stations KSSN04 and KSSN05 were located on the north and south side of West Point, respectively, KSHZ03 at Carkeek Park and LSKR01 at Alki Point. Ambient stations were located near Richmond Beach (JSVW04), Normandy Park (MTLD03), Golden Gardens (KSLU03) and Magnolia (KSYV02). Additionally, Suquamish Beach (OMHB) was sampled in 1999 to provide a reference station. However, a small outfall is located near this station that was not known at the time of sampling, making it unsuitable for a reference station. Therefore, this site was not sampled in 2000. All stations were sampled in August.

Beryllium, selenium, mercury, and silver were not detected in any samples, which is consistent with results from previous years. When detected, lead was at concentrations only slightly above the MDL. Lead was detected in all samples in 2000 and only two in 1999. This is likely due to a lower detection limit that was achieved using a new protocol. Copper and zinc were detected in all samples, at levels ranging from 3.23 to 24.2 mg/kg and 6.45 to 20.45 mg/kg, respectively. Copper was higher in 2000 compared to 1999 and 1998 at JSVW04, KSSN04, KSSN05, LSKR01 AND KSHZ03.

In the past few years, concentrations of chromium, nickel, and zinc have been higher in algae collected from the stations at West Point compared with other stations. Additional stations were sampled in 1999 and 2000 to determine if the pattern of elevated metals near West Point is a continuing trend. Stations were located on both the west and east side of the central basin as well as north and south of West Point. In addition, total and dissolved metals were measured in the water column at these stations.

Chromium, nickel and zinc were not found to be significantly higher in algae samples collected from West Point stations relative to the other stations in 1999 and 2000. Zinc and nickel concentrations in macroalgae were significantly lower at both West Point stations in 1999 and 2000 compared to 1998 concentrations. A summary of metal concentrations detected in algae samples from stations in 1998, 1999 and 2000 is provided in Table 3-28.

Table 3-28. Metal Concentrations in Macroalgae (mg/kg dry weight)

	JSVW04			KSYV04			KSSN04			KSSN05			LSKR01		
	2000	1999	1998	2000	1999	1998	2000	1999	1998	2000	1999	1998	2000	1999	1998
Arsenic	4.49	5.56	4.04	5.46	4.52	7.95	5.95	4.63	2.68	4.57	4.39	4.04	5.09	4.27	4.25
Cadmium	0.46	0.34	0.27	0.10	<0.16	<0.16	0.30	<0.16	0.35	0.22	0.24	0.13	0.30	0.29	0.55
Chromium	1.66	1.63	9.35	3.06	1.93	2.68	3.18	1.49	8.39	4.57	4.71	8.57	1.37	0.71	1.16
Copper	14.0	4.51	6.93	5.46	13.8	10.7	17.0	8.11	7.00	24.2	8.46	6.07	22.1	3.23	2.49
Lead	1.11	<1.8	2.67	0.956	1.97	2.05	0.859	<1.6	2.74	0.727	<1.3	<1.1	0.307	<2.3	<1.7
Nickel	2.44	4.15	10.6	3.51	2.55	10.9	3.92	3.79	30.2	6.10	6.24	10.7	2.70	2.14	2.38
Zinc	7.21	11.5	16.4	9.23	17.6	76.7	14.2	16.7	193	13.4	18.7	19.5	19.6	9.62	9.06

Additional sampling that began in 1999 allowed for a comparison between water column samples that were collected concurrently with algae. Correlation coefficients were calculated to determine if a relationship between metals in algae and dissolved metals in the water column exist. Individual metals were not found to be correlated at the $\alpha=0.5$ level. This may be due to a lack of power in the analysis resulting from the small sample size, as other researchers have found algae metals to be correlated with ambient water column metal concentrations. Researchers have also noted that salinity, water temperature, light intensity and growth rate all influence the uptake of metals. Additional samples at each site would be necessary to determine if this relationship exists.

